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# PLANT AND SOIL

International Journal of Plant Nutrition, Plant Chemistry, Soil Microbiology and Soil-borne Plant Diseases

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# PLANT AND SOIL

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CONTENTS: TABLE DES MATIÈRES: INHALT:


*F. Hagenzieker*, Soil-nitrogen studies at Urambo, Tanganyika Territory, East Africa . . . . . 97

*J. Hagin*, Comparison of availability of phosphorus from granulated and powdered superphosphate by calculations of yield curves related to the phosphorus added and found in soil and plant tests. . . . . 114

*L. H. Jones* and *D. A. Thurman*, The determination of aluminium in soil, ash and plant materials using Eriochrome Cyanine R.A. 131

*P. Schäfer*, Die Problematik der Bodenverdünnung durch Sand bei der pflanzenphysiologischen Gefäszmethode zur Bestimmung des im Boden vorhandenen pflanzenaufnehmbaren Nährstoffvorrates . . . . . 143

*E. W. Bolle-Jones*, Copper: Its effects on the growth and composition of the rubber plant *(Hevea brasiliensis)* . . . . . 160

*K. L. Bocock* and *O. J. W. Gilbert*, The disappearance of leaf litter under different woodland conditions . . . . . 179

Letter to the editors *K. H. Schütte*, Miero-nutrient deficiency and wilting in the radish . . . . . 186



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# SOIL-NITROGEN STUDIES AT URAMBO, TANGANYIKA TERRITORY, EAST AFRICA

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## SIDE DETAILS

Urambo is situated on the East African plateau at an altitude of approximately 3,500 ft. The area around shows an extremely mature topography. Drainage channels widen out to large flats that serve as temporary reservoirs for surface water run-off. The natural vegetation of the uplands is open deciduous woodland. In valleys and drainage channels which receive much of the seasonal floodwater, the tree growth gives way to a tall grass cover. The average annual rainfall is believed to lie between 30 and 40 inches, falling mainly in the months November to April. The dry season is absolute, in that no rain falls at all.

The main soil series are found in a catenary sucession. Red sandy loams (R.S.L.) are situated at the top end of the slope. Further down the soils change via the pallid loamy sands (P.L.S.) into grey sands (G.S.), which are followed by a series ranging from coarse sands to sandy clays. This latter series of "valley and drainage channel soils" receives a seasonal excess of water and is not used for arable agriculture. The upland soils are many feet deep and freely draining. The topsoils, of about 6 inches thick, are slightly darker in colour than the corresponding subsoils due to the presence of one to two per cent organic matter. Furthermore, they show an accumulation of calcium and phosphates. The reaction of the topsoils fluctuates around the neutral point. The pH of the subsoils lies between one and two units lower. The profiles of the arable soils show a fairly uniform mechanical composition. Clay contents range from 15 to 30 per cent in the R.S.L. to some 5 per cent in the G.S. Silt is almost absent. The contents of fine and coarse sand are approximately equal.

Field experiments indicate that the soils carry an adequate supply of potash, calcium and magnesium for the optimum performance of most crops. The same holds for trace elements. On the R.S.L. positive responses to phosphatic fertilizers are rare and small. On the lighter textured soils the responses are bigger and they occur more frequently. The nitrogen status is extremely low. Non-leguminous crops do not give a good yield unless they receive a dressing with a nitrogenous fertilizer. (For further details see Ref. [1 4 5 7]).

## A. LABORATORY INVESTIGATIONS

*Determinations carried out*

I) From August 1951 until the end of the year fluctuations in ammonia and nitrate nitrogen, and in moisture content were followed at weekly intervals on soils from four different sites: —

1. R.S.L.: kept bare (Graph 1)
2. P.L.S.: kept bare
3. G.S.: kept bare
4. G.S.: kept under sorghum which was planted in May 1951, at the end of the previous rainy season (Graph 2).

At the beginning of 1952 the release of mineral nitrogen from a ploughed-in green manure was studied at intervals of 3 and 4 days on soils from three different sites: —

5. G.S.: kept under sorghum, planted as on Site 4; ploughed in on 9/2/52 and kept bare afterwards (Graph 3).
6. G.S.: kept under a mixed stand of sunn-hemp (*Crotalaria juncea*) and velvet bean (*Stizolobium sp.*), planted as on Site 4; ploughed in on 14/2/52 and kept bare afterwards (Graph 4)
7. G.S.: kept under an established ley of Rhodes grass (*Chloris gayana*); ploughed in on 7/2/52 and kept bare afterwards (Graph 5)

Soil samples were taken at three depths: —

*a.* 0–10 cm – topsoil
*b.* 10–20 cm – subsoil
*c.* 40–50 cm – sub-subsoil

II) Total soil nitrogen was determined on top-, sub- and sub-subsoil samples, taken from Sites 1, 2, 3 and 4. The samples were taken in the first week of September 1951, before the rains had started.

III) Incubation tests on the nitrogen mineralisation in the top-soils of the R.S.L. were carried out (Graph 6). Samples were taken from two adjacent sites: —

1. A field that had been under continuous cultivation since it was cleared from bush in 1948.
2. The residential area of the Agricultural Research Station. The natural vegetation in this area, the open wood, is more or less preserved.

*Analytical methods*

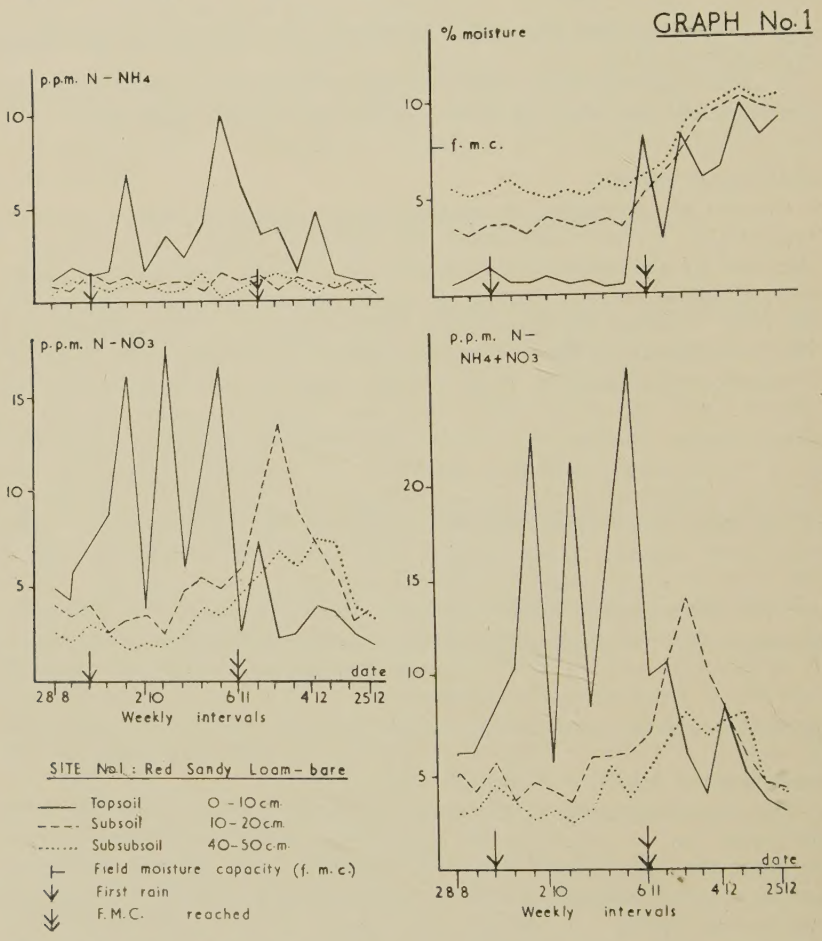
For nitrogen and moisture determinations composite samples representing four sites per 1/10 acre were taken. The Kjehldahl method given by Piper [8] was used for the determination of total soil nitrogen. Ammonia and nitrate determinations were carried out on moist samples that came straight from the field. Leaching was done with a normal solution of NaCl acidified with HCl to a pH between one and two, according to the method of McLean and Robinson (described by Piper [8]). The quantity of leaching solution employed was to the extent of five times the weight of the moist soil. For the determination of ammonia a sample of the leacheate was distilled with NaOH in a micro steam-distillation apparatus, as developed by Parnas and Wagner (described by Milton and Waters [6]). Subsequently, the nitrates of the same sample were reduced to ammonia with Devarda's alloy in the distillation unit and finally distilled over. It has been assumed throughout the whole of the investigation that the amounts of nitrites are too small to warrant their separate determination. Nitrites present, if any, have been incorporated in the nitrate figures. The ammoniacal distillates were collected in an alcoholic solution of boric acid as described by Parnas and Wagner (see Ref.[6]). Titration was done with $5.10^{-4}$ *N* HCl. The indicator used was brom-cresol-green, screened with methyl-red. Soil moisture was determined by drying at 105°C to constant weight. For field-moisture capacities the method given by Piper [8] was followed.

The incubation tests on nitrogen mineralisation were carried out in the following way. A composite soil sample was split into 12 portions, each weighing the equivalent of 20 g of 105°C oven-dry soil. The subsamples were spread out in Petri dishes and their moisture contents were raised to ten per cent by the addition of distilled water. The simultaneous incubation of the subsamples took place in the dark at 25°C. At successive intervals of three days determinations for ammonia and nitrates were carried out on one of the 12 subsamples. The initial contents of mineral nitrogen were determined before the test was started.

All nitrogen data have been expressed in parts per million of elemental nitrogen (ppm N), based on 105°C dry soil. Soil moisture has been given on a dry-weight basis in percentages. Data for mineral nitrogen and for soil moisture represent the means of two determinations. Variations in the order of 2 ppm N and of 2.5 per cent moisture must be ascribed to errors in sampling and in the analytical techniques.

*Results and discussion*

The course of fluctuations in mineral nitrogen and in moisture content on site 1 are shown in Graph 1. Sites 2 and 3 produced




similar results. However, the maxima of both ammonia and nitrates were less pronounced, as may be seen from Table I.

On bare land the N flush started when the first rain had fallen. The rainfall records from the beginning of the wet season until November 22nd, 1951, are given in Table II.

The N flush was confined to the topsoil so long as no significant changes in soil-moisture content took place. It lasted for approximately six weeks. When the field-moisture capacity had been

TABLE I

Maxima for ammonia, nitrate and total nitrogen in ppm N

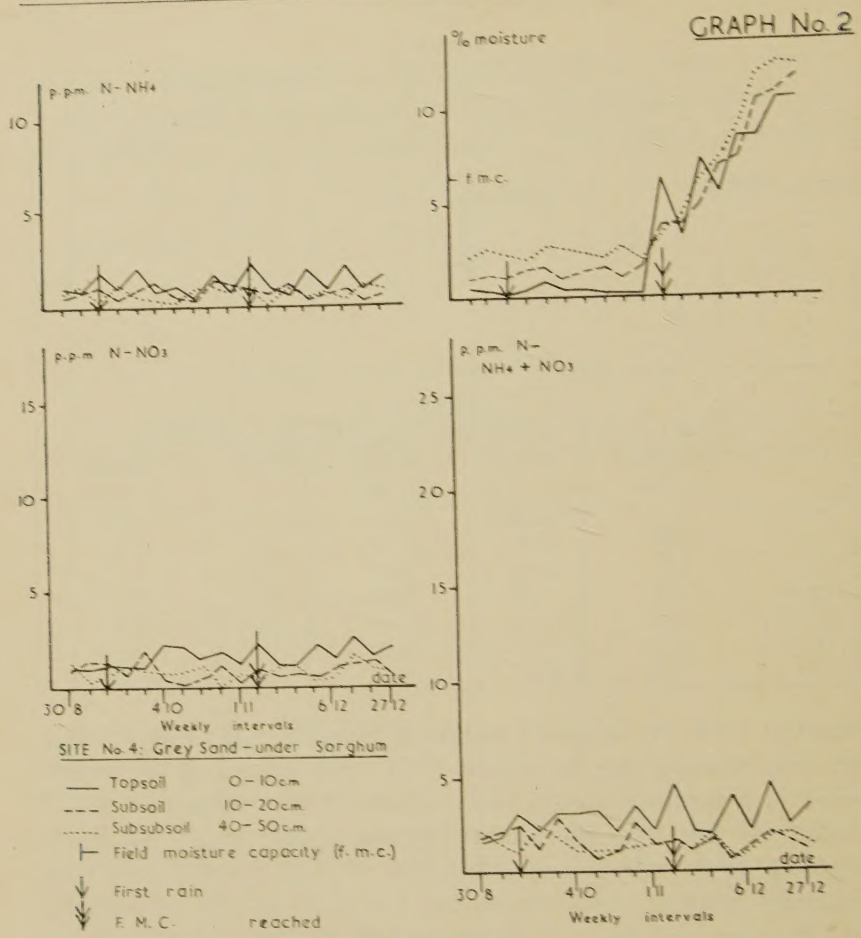
| No. Site | $(NH_4)$ — N | | | $(NO_3)$ — N | | | $(NH_4 + NO_3)$ — N | | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth | | | Depth | | | Depth | | |
| | *a.* | *b.* | *c.* | *a.* | *b.* | *c.* | *a.* | *b.* | *c.* |
| 1. | 10 | 2 | 2 | 18 | 14 | 7 | 26 | 14 | 8 |
| 2. | 8 | 2 | 2 | 17 | 13 | 7 | 23 | 13 | 8 |
| 3. | 2 | 2 | 2 | 11 | 7 | 5 | 13 | 9 | 6 |
| 4. | 2 | 2 | 2 | 3 | 2 | 2 | 5 | 3 | 2 |
| 5. | 2 | 5 | 3 | 10 | 10 | 15 | 12 | 15 | 18 |
| 6. | 9 | 3 | 4 | 11 | 7 | 7 | 20 | 10 | 9 |
| 7. | 4 | 3 | 2 | 7 | 6 | 5 | 11 | 9 | 7 |

TABLE II

Rainfall records for the first ten weeks of the 1951 rainy season

| Date | Rainfall in inches | Date | Rainfall in inches | Date | Rainfall in inches |
|---|---|---|---|---|---|
| 10/9 | trace | 3/11 | 0.06 | 14/11 | 0.13 |
| 11/9 | 0.05 | 5/11 | 0.60 | 17/11 | 0.28 |
| 29/9 | 0.34 | 6/11 | 0.45 | 18/11 | 0.80 |
| 12/10 | 0.01 | 7/11 | 0.32 | 19/11 | 0.72 |
| 15/10 | trace | 8/11 | 0.04 | 20/11 | 0.98 |
| 16/10 | trace | 9/11 | 0.02 | 21/11 | 1.15 |
| 2/11 | 0.28 | 13/11 | 0.10 | 22/11 | 0.06 |

reached both the ammonia and nitrate figures of the topsoil began to drop towards the dry-season level. This started in the second week of November when a total amount of two inches of rain had fallen. At this time the nitrate content of the deeper soil layers went up. In the subsoil a maximum was reached two weeks after the moisture content of the topsoil had exceeded the field capacity for the first time. For Site 1 this happened on the 20th November when a total of 5.18 inches of rain had fallen. By then both the sub- and the sub-subsoil had become saturated beyond their field capacity. Four weeks later the nitrate content had fallen back to its original level. In the sub-subsoil the nitrate peak occurred two to three weeks after it was found in the subsoil and five to six weeks after the N flush in the topsoil had ended. This was in the first and second week of December. In the last week of December, at the same time as was found for the subsoil, the dry-season level had been resumed. The nitrate flush in the sub-subsoil occurred two to three weeks after the moisture content of that layer had exceeded the field capacity. Changes in the ammonia content of the sub- and the sub-subsoil could not be detected. Of a total-nitrogen content of




322 ppm in the topsoil of Site 1 a maximum of 26 ppm was detected as mineral nitrogen at the peak of the flush. This is less than 8 per cent. The percentages are even smaller on the other sites as may be seen by comparing Table I with Table III.

TABLE III

Total soil-nitrogen content, determined before the rains had started, in ppm N. Means of 7 replicates ($\bar{x}$) and standard error($s$)

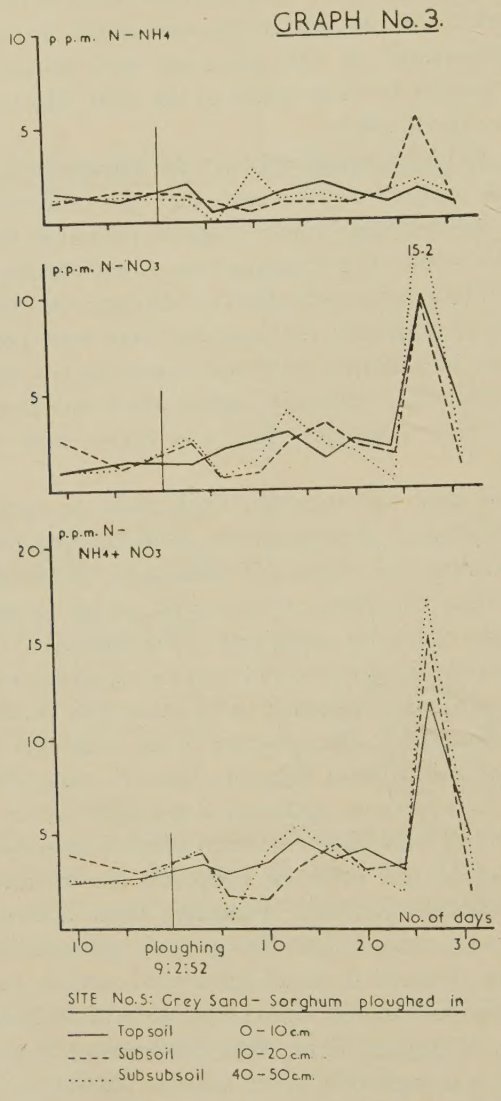
| No. Site | *a*: Topsoil | | *b*: Subsoil | | *c*: Sub-subsoil | |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ |
| 1. | 332 | 17 | 199 | 16 | 151 | 8 |
| 2. | 316 | 13 | 208 | 5 | 195 | 6 |
| 3. | 301 | 23 | 92 | 4 | 76 | 7 |
| 4. | 289 | 20 | 138 | 9 | 87 | 8 |

Striking features during the N flush in the topsoil were the very pronounced maxima and minima in both ammonia and nitrate content. These maxima and minima did not occur in the nitrate flush that was found in the sub- and in the sub-subsoil. In the incubation tests the fluctuations in the ammonia and nitrates that were released were similar to those found in the field. The results of these tests are shown in Graph 6.

Other facts to be observed are that the nitrate flush became less pronounced at greater depths and that the amount of mineral nitrogen that was released from a cropped topsoil in the incubation tests was of the same magnitude as that found during the N flush in the topsoil of bare land under field conditions. Also, the maximum concentrations of ammonia and nitrates that were released in the incubation tests of a sample that was taken from a site where the natural vegetation was virtually undisturbed was almost twice as high as that from a sample that was taken from an adjacent cropped field.

It is thought that the recorded flush must be ascribed chiefly to the microbiological decomposition of N-bearing organic compounds. Considering the mineral-N release in the incubation tests it is unlikely that the flush is the result of an accumulation of nitrogen brought down by rainwater [9]. Furthermore, the amounts with which the soil-nitrogen content may be raised by non-symbiotic N fixation are generally regarded to be much less than the quantities that were found [3 9]. The absence of an ammonia flush in the sub- and in the sub-subsoil suggests that N mineralisation only takes place in the toplayers, although a nitrogen source is available deeper down. In all likelihood the main sources of mineral nitrogen are the residues of the previous cropping season and the dead bodies of soil micro-organisms. Assuming these statements to be correct it is not surprising to find that greater quantities of ammonia and nitrates are released from an incubated sample that is taken from a soil under its natural vegetation cover than from a sample that comes from a cropped field. Also, the amount of nitrogen that is released from a ploughed-in green manure should be of the same magnitude as the amount of N that is found during the early season flush. This indeed was the case as may be seen from Table I. Differences in the maximum mineral-N contents under bare-soil conditions during the flush must, in the first instance, be traced

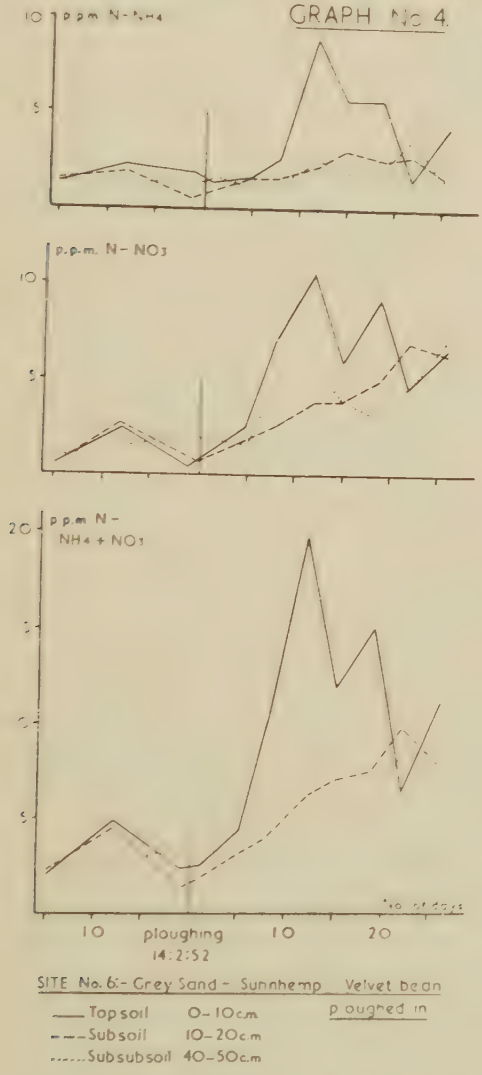
back to differences in the amounts and in the composition of the crop residues that were left behind and ploughed under. The recorded




nitrate concentrations are much lower than those found in Uganda [2]. They are more in the order of those reported from the Sudan and elsewhere [9].

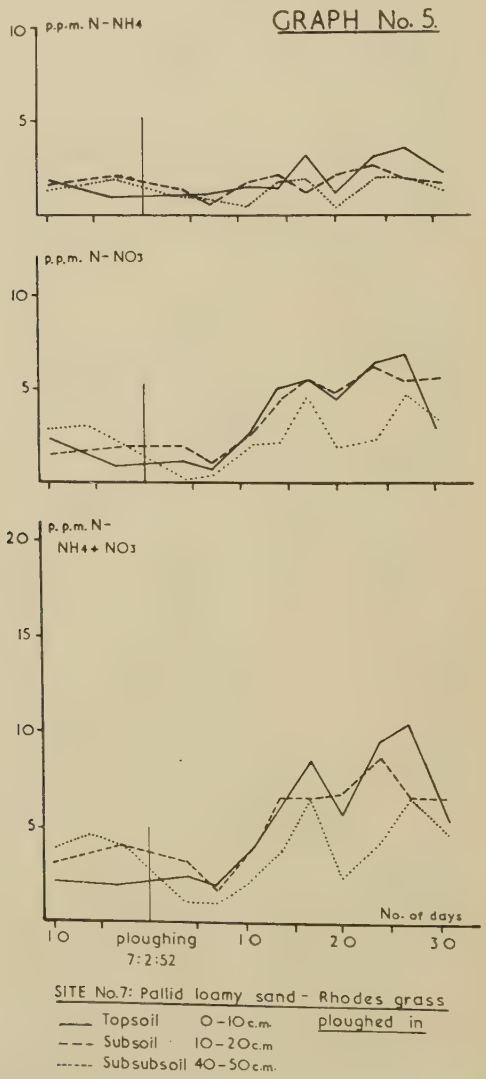
Apparently ammoniacal nitrogen is quickly oxidised to nitrates,

which are leached down into deeper soil layers when the field capacity has been exceeded. The less pronounced maxima of nitrate nitrogen in the sub- and in the sub-subsoil may be explained through




re-utilisation of part of the mineralised nitrogen by the microbiological population of those layers. Undoubtedly a proportion of the nitrates will be leached out completely.

Contrary to field conditions the movements of nutrient salts in solution could not take place in the incubation tests. Consequently a possible explanation for the topsoil maxima and minima in $NH_4$




and in $NO_3$ nitrogen being caused by evaporation and leaching respectively has been ruled out. The absence of fluctuations in soil-moisture content during the time of the N flush in the topsoil

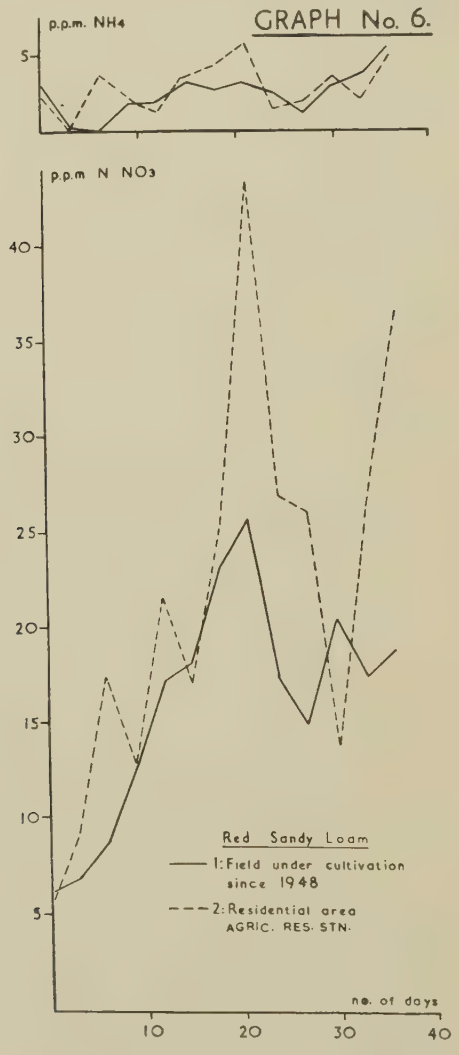
are in agreement with this point of view. A probable explanation for the phenomenon are fluctuations in the microbiological population.

No fluctuations in mineral nitrogen were observed on Site 4. The analytical results are shown in Graph 2. On the low-lying and relatively moist G.S. a crop can easily survive the dry season. Apparently sorghum, having a root system that penetrates the upper soil layers intensively, traps most, if not all, of the nitrogen flush.

The results of the determinations that were carried out on Sites 5, 6 and 7 are shown respectively in Graphs 3, 4, and 5. During most of the time that the investigations lasted the soil-moisture contents had exceeded the field capacities. Thus leaching took place almost continuously. This may explain why the sub- and the sub-subsoil rise in nitrate content on all the three sites took place at approximately the same time as that in the topsoil. The general patterns of nitrogen release from a ploughed-in green manure was the same as that of the early season flush. The temporary increase in ammonia content was confined to the topsoil. Except in the case of sorghum the nitrate flush became less pronounced at greater depths. As the nitrogen release from the ploughed-in sorghum was only short lived it may well be that the intervals in sampling time of 3 and 4 days obscured the results. In the topsoil higher nitrate figures might have been found than in the sub- and the sub-subsoil if sampling had been done more frequently. The first increase in ammonia and nitrate content occurred between 10 and 25 days after the ploughing in of the green manures; sunn-hemp being the first and sorghum the last crop to release nitrogen. For sorghum the N flush did not last much longer than 5 days as against a minimum of 3 to 4 weeks in the case of Rhodes grass and a mixture of sunn-hemp and velvet bean. As has been remarked before, the amounts of nitrogen that were mineralised from the ploughed-in green manures are of the same order as those found in the early season flush. The absolute magnitude of these data will depend on the composition and the amount of green matter that was ploughed under.

The agricultural implications of the above results may be summarised as follows. If no nitrogenous fertilizers are used higher yields may be expected in the first than in latter seasons after the

forest has been cleared. The application of nitrogenous fertilizers in the seedbed will lead to a smaller response than when given as a topdressing. Early planting may lead to a considerable




LABORATORY INVESTIGATIONS.

saving in the use of nitrogenous fertilizers. Depending on the amount and the intensity of the rainfall in the first month of the wet season it is unlikely that a crop will profit from the early N

flush if planted later than the middle of December. Generally speaking it would be advisable to plant as soon as enough rain has fallen to secure an early growth that is not hampered by lack of water. If early planting cannot be done the N flush may be conserved and released at a later date by trapping the nitrates with an already established or early planted green manure that is ploughed in afterwards. Probably a leguminous rather than a non-leguminous crop will give better results. It would be advisable to plant within a few days after the green manure has been ploughed in.

### B. FIELD EXPERIMENTS

*Experiments carried out*

The field experiments were laid out in an attempt to correlate the results of the laboratory investigations with crop production. Randomised blocks and lattice squares were used invariably. In all experiments maize (var. Katumbili) was used as a test crop and a basic dressing of triple-superphosphate at a rate of one cwt per acre was given. The results are expressed in lbs of grain per acre.

One experiment was conducted to compare the effects of a seedbed application of sulphate of ammonia with a topdressing. The most appropriate time for a topdressing was studied in another trial. Two experiments were laid out to elucidate the relationship between planting date and nitrogen requirements. In other words, the experiments were designed to find out whether profitable use could be made of the early N flush by planting early. Another three experiments were laid out to test green manures as to their effectiveness in supplying nitrogen. In the case of sunn-hemp being used as a green manure the crop was ploughed in when in full bloom.

*Results and discussion*

As may be seen from Table IV a topdressing of sulphate of ammonia is superior to an application before or at planting time. The experiment from which the data have been taken was conducted on the P.L.S.

The topdressing can be done soon after planting. Even on the quickly draining G.S. the difference in yield between a topdressing done one week after emergence and one two weeks later is only slight (and not statistically significant), as can be observed from

the results given in Table V. The topdressing was done with sulphate of ammonia at a rate of 2 cwt per acre.

The "nil" yields of 1040 and 360 lbs per acre, shown respectively in Tables IV and V, mainly reflect differences in the original nitrogen status of the soil. If no nitrogenous fertilizers are used yields as high as 1000 lbs per acre are only likely to be harvested from virgin land.

TABLE IV

| The effects of topdressings versus a seedbed application of sulphate of ammonia. Yield in lbs of grain per acre. L.S.D. = 90 (5% level) | | |
|---|---|---|
| Rates of S.A. in cwt per acre | S.A. applied at planting time | S.A. top-dressed 3 weeks after emergence |
| Nil | 1040 | 1040 |
| 2 | 1260 | 1620 |
| 3 | 1210 | 1800 |

TABLE V

| The effects of different times of topdressing with sulphate of ammonia | |
|---|---|
| No. of days after emergence at which the topdressing was done | Yield in lbs of grain per acre L.S.D. = 90 (5% level) |
| No S.A. given | 360 |
| 8 days | 1070 |
| 24 days | 1100 |

As can be seen from Table VI early planting may lead to a reduction in the requirements of nitrogenous fertilizers. Plantings done later than the middle of December failed to utilise the early season N flush. These findings are in accordance with the conclusions

TABLE VI

| The effects of early planting in combination with rates of sulphate of ammonia. Yield in lbs of grain per acre. | | | | |
|---|---|---|---|---|
| Rates of S.A. top-dressed in cwt per acre | R.S.L. L.S.D. = 145 (5% level) | | G.S. L.S.D. = 125 (5% level) | |
| | Dates of planting | | | |
| | 9/12/51 | 31/12/51 | 22/11/51 | 17/12/51 |
| Nil | 980 | 80 | 660 | 210 |
| 1 | 2230 | 1565 | 1665 | 970 |
| 2 | 2245 | 1775 | 1625 | 1300 |
| 3 | — | — | 1750 | 1600 |

drawn from the laboratory investigations. In the experiment that was conducted on the G.S. the agricultural value of the flush appeared to be equivalent to a topdressing of approximately 2 cwt per acre of sulphate of ammonia.

In Table VII the effects of three green manures are shown. The experiment was laid out on the G.S. and the green manures, planted in May, survived the dry season. No nitrogenous fertilizers were given.

TABLE VII

The effects of three different green manures
Yield in lbs of grain per acre. L.S.D. = 130 (5% level)

| Type of green manure | No. of days between the ploughing in of the green manure and planting | |
|---|---|---|
| | 17 | 32 |
| Bare | 340 | 360 |
| Rhodes grass | 490 | 390 |
| Sorghum | 705 | 410 |
| Sunn-hemp and velvet bean | 905 | 745 |

Assuming that the beneficial effects are due mainly to an increased supply of nitrogen the insignificant response to sorghum at the second planting date is in accordance with the results of the chemical analyses. Also the small drop in the response to sunn-hemp between the first and the second planting date agrees well with the laboratory results. A bigger response to Rhodes grass would have been expected. However, in the experiment the Rhodes grass was planted shortly before the dry season had commenced and when the green manure was ploughed in only a limited growth had been made. On the other hand the chemical analyses were carried out on a site that had a well-established grass ley ploughed in.

On the dryer R.S.L. where a crop will not survive the dry season, the N flush may be trapped by an early planted green manure. Table VIII shows the results of an experiment laid out on the R.S.L. in which the green manures were planted on 20 11 51. The test crop, maize, was planted one week after the ploughing was done on 29/1/52.

As would have been expected, sunn-hemp as a green manure gave a greater increase in yield than did sorghum. Apparently a topdressing of 2 cwt of sulphate of ammonia per acre was ample to

secure optimum yields. The equivalent value of sunn-hemp was less than a 2-cwt topdressing of ammonium sulphate per acre.

TABLE VIII

The effects of two green manures alone and in combination with a topdressing of sulphate of ammonia. L.S.D. = 200 (5% level)

| Type of green manures | No nitrogen fertilizers | S.A. top-dressed at a rate of 2 cwt per acre |
|---|---|---|
| Bare | 690 | 2415 |
| Sorghum | 1165 | 2465 |
| Sunn-hemp | 1745 | 2490 |

An attempt was made to determine more accurately the green manuring value of a sunn-hemp and velvet bean mixture as a source of nitrogen. The experiment was conducted on the G.S. and the green manure was planted in May at the end of the previous rainy season. The results are given in Table IX.

TABLE IX

The effects of a mixed stand of sunn-hemp and velvet bean as a green manure, alone and in combination with rates of sulphate of ammonia. Yield in lbs. of grain per acre. L.S.D. = 175 (5% level)

| Rates of S.A. top-dressed in cwt per acre | Bare | Green manured with sunn-hemp and velvet bean |
|---|---|---|
| Nil | 390 | 1015 |
| 1 | 870 | 1930 |
| 2 | 1560 | 2200 |

It would appear that the green manure had supplied a quantity of nitrogen equivalent to a topdressing of one to 2 cwt of sulphate of ammonia per acre. The data of Table VI would suggest that even with ample dressings of N and P fertilizers the G.S. do not give higher yields than some 1700 to 1800 lbs of grain per acre. Therefore the high yields resulting from a combination of a green manure and a sulphate-of-ammonia dressing can hardly be explained by assuming that the green manure only contributes to an increase in yield by means of an additional supply of nitrogen. It is thought that in addition to nitrogen the availability of phosphates has been increased by the green manure. On a soil like the R.S.L. that rarely responds to phosphate fertilisation the increase in yield due to

green manuring would have to be explained solely by an increase in the supply of nitrogen. Provided the fertilizer dressing is high enough on the R.S.L. the combination of a green manure and a nitrogenous fertilizer should not lead to higher yields than those obtained by the artificial alone. The data that were given in Table VIII are in accordance with this hypothesis.

## SUMMARY

Chemical analyses indicate a topsoil flush of mineral nitrogen at the onset of the rainy season. The flush does not last longer than six weeks. After that the ammonia and nitrate contents fall back to small and fairly constant values. In the presence of an actively growing crop no fluctuations in mineral nitrogen can be detected. The flush must result from the mineralisation of organic material that is derived from crop residues of the previous season and from the dead bodies of micro-organisms. The extent to which nitrogen is released from a ploughed-in green manure is of the same order as the amount of nitrogen that is mineralised at the first rains. Differences between the time of appearance after ploughing and the length of time during which this flush lasts seem to be related to the type of green manure.

Field experiments were conducted to study the most efficient use of nitrogenous fertilizers. A topdressing of sulphate of ammonia is superior to a seedbed application. Considerable savings in the use of nitrogenous fertilizers can be obtained through planting early in the season. At least part of a crop's nitrogen needs can be met by making use of a green manure.

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# COMPARISON OF AVAILABILITY OF PHOSPHORUS FROM GRANULATED AND POWDERED SUPERPHOSPHATE BY CALCULATIONS OF YIELD CURVES RELATED TO THE PHOSPHORUS ADDED AND FOUND IN SOIL AND PLANT TESTS

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## INTRODUCTION

The primary source of phosphorus for Israel agriculture is superphosphate in powder form. There is a general tendency in the fertilizer industry to produce granulated fertilizers. However there is no agreement about the agronomic value of fertilizer granulation, as shown in the works of Starostka *et al.*[22], Mehring *et al.*[14], Skinner *et al.*[20], Ovens *et al.*[17], and as reviewed by Rogers *et al.*[19]. It seems, that if any beneficial effect of granulation can be expected, it should be most apparent in the case of water-soluble materials, such as superphosphate. Granulated fertilizer may also be beneficial under soil conditions conducive to phosphorus fixation.

The aim of the present investigation was to study under greenhouse conditions the differences, if any, in availability of phosphorus given as superphosphate in the powder form and in a granulated one.

## MATERIALS AND METHODS

Four soils from different regions in Israel were used in the investigation: A clay soil from Hazorea (Esdraelon Valley), a clay soil from Degania (Jordan Valley), a sandy loam from Gilat in the Negev region and a sandy soil from Rehovot in the Coastal Plain. The four soils vary considerably in their mechanical composition, as well as in their calcium carbonate content. Two of them, namely Hazorea and Rehovot, have a low calcium carbonate content and the other two, Degania and Gilat, are calcareous. Some of their characteristics are given in Table I.

TABLE I

Some characteristics of the experimental soils

| Characteristics | Hazorea | Degania | Gilat | Rehovot |
|---|---|---|---|---|
| $CaCO_3$ . . . . . % | 1.2 | 39.2 | 12.8 | 0.0 |
| Organic mtater . . . . . % | 1.4 | 1.4 | 0.6 | 0.5 |
| $EC_{25}$ . . . . . millimhos/cm | 0.80 | 1.52 | 0.70 | 0.54 |
| pH . . . . . | 7.4 | 7.4 | 7.6 | 7.0 |
| Field capacity . . . . . % | 48.8 | 27.8 | 15.5 | 7.8 |
| Soluble P in water extract . . ppm | 3.4 | 0.5 | 1.2 | 3.5 |
| Soluble P in $NaHCO_3$ extract . ppm | 14.2 | 10.0 | 6.1 | 13.3 |
| Soluble P in $NH_4F$ extract . . ppm | 9.6 | 5.1 | 7.8 | 12.9 |
| Soluble P in presence of Na-permutite . . . . . ppm | 43.1 | 74.3 | 30.0 | 5.3 |

Calcium carbonate was determined gasometrically. Organic matter was found by Tiurin's wet-oxidation method. Electrical conductivity was determined in the soil paste extract and the pH was determined in the soil paste [18]. The "field capacity" was determined, in order to enable suitable watering of the soils in pots, as described elsewhere [11]. Soluble phosphorus was determined by the following methods: 1) water extract by the Bingham method [2], 2) sodium bicarbonate extract according to Olsen [16], 3) ammonium fluoride extract as described by Bray and Kurtz [7] and 4) by Moeller and Morgensen's Na-permutite method [15]. Phosphorus was determined by the molybdic-acid colorimetric method [8]. The phosphorus in plants was determined using oven-dry material, ground in a Willey mill. The plant material was mixed and further treated according to Richards [18].

The soils were crushed, sieved through a 5 mm hole sieve and transferred into greenhouse pots (6 kg per pot). The superphosphate fertilizers were mixed with the upper half of the soil in each pot. (The superphosphate fertilizers used were obtained in a granular form ranging in size between 2 and 4 mm, supplied by Fertilizers and Chemicals Ltd., Haifa, Israel). For the granular superphosphate treatments the fertilizer was given as obtained. For the powder treatments the granules were crushed and passed through a 100-mesh sieve. The fertilizer contained 7.26 per cent water-soluble P (16.5% $P_2O_5$).

Phosphorus fertilizers were given in powder and granular form at four levels:

1) No P fertilizer
2) 5 kg P per dunam (1000 $m^2$) — 20 mg P per 1 kg of soil
3) 10 kg P per dunam (1000 $m^2$) — 40 mg P per 1 kg of soil
4) 15 kg P per dunam (1000 $m^2$) — 60 mg P per 1 kg of soil

All pots received the same amount of nitrogen and potassium, namely 1 kg N per dunam as ammonium sulphate and 5 kg K per dunam as potassium chloride. These two fertilizers were dissolved in water and were added in solution at the first irrigation of the pots.

Clover was sown in the pots in a greenhouse on December 3, 1955. After emergence the plants were thinned to ten per pot. By frequent watering with

distilled water the moisture content of the soils was kept approximately at "field capacity", determined by the loss in weight of the pots due to evapotranspiration.

The clover was cut four times on the following dates: 1) January 30, 2) March 7, 3) April 9, and 4) May 10.

At the fourth cutting most of the plants were in the flowering stage. After each cutting the plants were oven dried and weighed. Soil samples were taken with a small soil auger from three locations in each pot approximately at the time of the first cutting and after the fourth cutting. The samples from the three borings were mixed before analysis. The soils in the pots were not irrigated during the summer months. At the beginning of September 1956 the pots were again irrigated and nitrogen (20 kg N per dunam) and potassium (6 kg K per dunam) fertilizers were added to the irrigation water.

Corn was sown on September 9, 1956 and thinned out to 3 plants per pot. Two months later the corn plants were cut, at the onset of flowering. The green plants were oven dried and weighed.

## RESULTS

### *Yields of clover*

Oven-dry weights of the clover plants per pot were recorded after each cutting. In Figure 1 the cumulative mean weights per cutting and per treatment are given.

A Mitscherlich growth curve was fitted to the data by the least squares method, as described by Eid, Black and Kempthorne [9]. These curves, calculated for the total yields of clover in the four soils, are drawn in Graphs 1*a–d*.

The yield curve for clover in the soil from Hazorea is very similar for both types of superphosphate fertilizer, *i.e.* the granular and powder forms. The maximum yield obtainable is actually the same, although the rate of response to the granular form is slower. Similar results were obtained in the soil from Gilat.

A different picture is seen by examination of the yield curves in the soils from Rehovot and Degania. In the soil from Rehovot the yields and the response to superhosphate are, in general, relatively low. However, the granular form produced a more rapid response than the powder one. In the soil from Degania, a highly calcareous one, the granular form of superphosphate was only slightly effective and the yield response was very low as compared to response to the powder form. Actually, according to the yield curves it seems as if two entirely different fertilizers were used.

Analysis of variance of the clover dry yields revealed that the differences between fertilizer levels in powder form are significant,

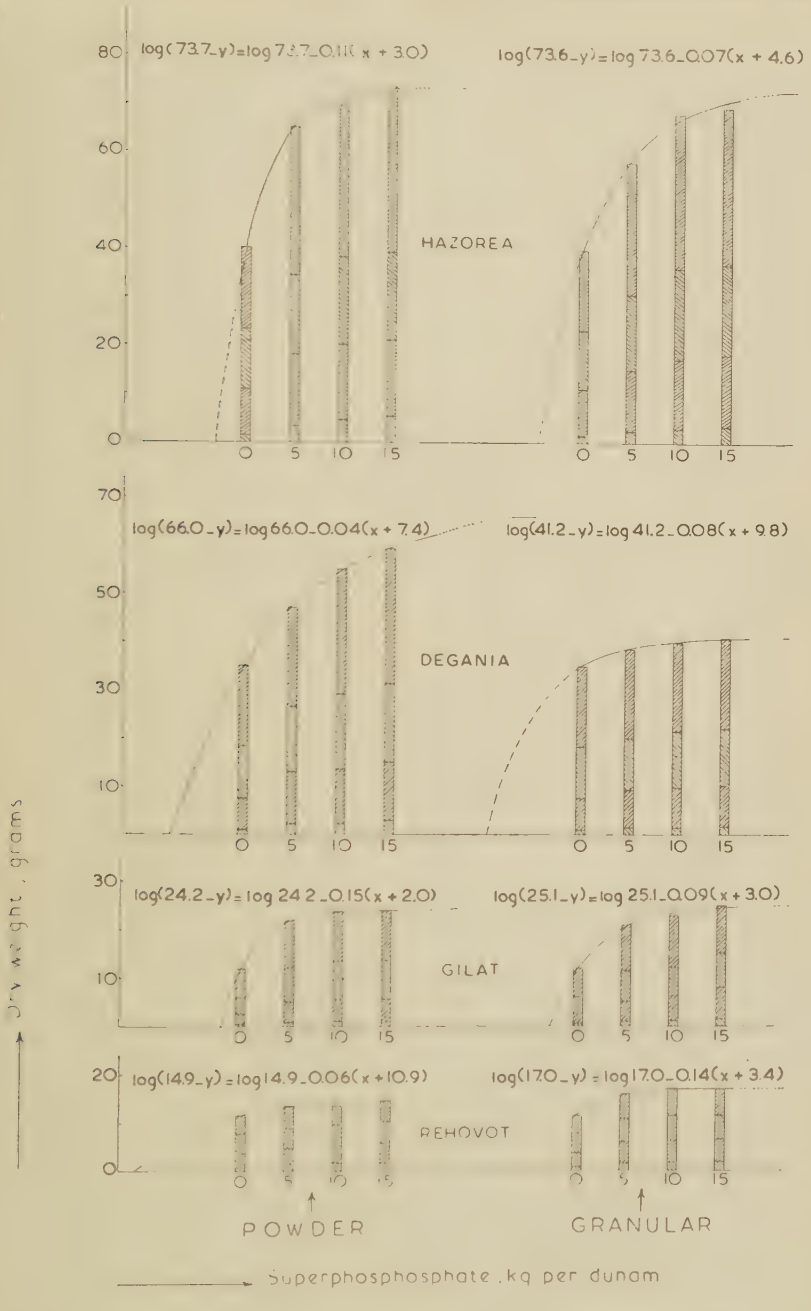


Fig. 1. Yields of clover in pot experiments with four typical Israeli agricultural soils.

however, these differences in granular form are not significant. The variation in yields between replicates was higher on the granular superphosphate than on the powder form. The differences between the yields in the control pots and the treatments containing powder or granular fertilizers are highly significant. A highly significant difference between yields obtainable on the four soils used was found. It is also apparent that the fertilizers act differently in different soils as the interaction between soils and fertilizers is highly significant.

Phosphorus was determined in the oven-dried plants. A composite sample was formed, which included the plants from four cuttings and thus represented the total yields. Also one sample from the four replicates was formed and a mean sample was analyzed. The results of these analyses are given in Table II. There the percentage of P

TABLE II

Percentage of P in oven-dry clover plants and mean plant content of P per pot

| Soil | Superphosphate | | P in clover dry matter | Plant content of P |
|---|---|---|---|---|
| | Form | Kg/dunam | % | per pot mg |
| Hazorea | | 0 | 0.117 | 47 |
| | Powder | 5 | 0.180 | 118 |
| | | 10 | 0.215 | 151 |
| | | 15 | 0.285 | 211 |
| | Granular | 5 | 0.130 | 76 |
| | | 10 | 0.175 | 120 |
| | | 15 | 0.247 | 173 |
| Degania | | 0 | 0.155 | 54 |
| | Powder | 5 | 0.165 | 77 |
| | | 10 | 0.190 | 105 |
| | | 15 | 0.203 | 120 |
| | Granular | 5 | 0.165 | 63 |
| | | 10 | 0.180 | 72 |
| | | 15 | 0.167 | 69 |
| Gilat | | 0 | 0.087 | 11 |
| | Powder | 5 | 0.235 | 52 |
| | | 10 | 0.290 | 70 |
| | | 15 | 0.285 | 68 |
| | Granular | 5 | 0.163 | 34 |
| | | 10 | 0.175 | 40 |
| | | 15 | 0.190 | 47 |
| Rehovot | | 0 | 0.240 | 28 |
| | Powder | 5 | 0.480 | 65 |
| | | 10 | 0.627 | 85 |
| | | 15 | 0.730 | 107 |
| | Granular | 5 | 0.400 | 64 |
| | | 10 | 0.480 | 82 |
| | | 15 | 0.890 | 151 |

in dry plant matter is recorded and the mean content of plant phosphorus per pot was calculated from the data on P percentage and the mean yields of clover per pot as given in Figure 1. In general, it may be concluded from Table II that the extraction of phosphorus from the soil by the plants was not parallel to the yields obtained. The differences between soils in phosphorus contents are smaller than those for the yield of clover.

*Yields of corn*

In order to obtain an indication of the residual value of phosphorus after the clover crop, corn was grown on the same soils. The mean dry weights of the corn plants are recorded in Table III.

TABLE III

Mean yields of corn plants (grams dry matter).

| Superphosphate on previous crop | | Hazorea | Degania | Gilat | Rehovot |
|---|---|---|---|---|---|
| Form | Kg/dunam | | | | |
| | 0 | 22.2 | 31.9 | 16.7 | 24.2 |
| Powder | 5 | 40.0 | 38.3 | 34.3 | 24.0 |
| | 10 | 55.0 | 40.2 | 33.8 | 25.0 |
| | 15 | 53.5 | 43.7 | 31.8 | 25.0 |
| Granular | 5 | 39.9 | 39.8 | 27.6 | 24.0 |
| | 10 | 49.7 | 36.6 | 33.8 | 25.0 |
| | 15 | 48.2 | 37.0 | 33.4 | 25.1 |

The yields of corn show a high residual effect of superphosphate in three out of the four soils tested. No residual effect is noted on the soil from Rehovot. However the yields obtained in this soil were generally low. No attempt was made to draw yield curves as a function of the amount of phosphorus added to the previous crop. This relation does not seem realistic in spite of the fact that the yields obtained tend towards a Mitscherlich logarithmic curve.

Analysis of variance of the data showed significant and highly significant differences between the treatments.

*Extractions of soluble phosphorus from soils*

The soil samples taken from the pots at the beginning of the experiment, were analyzed for soluble phosphorus in various extractants. The results presented in Table IV are means of analyses in four pots per treatment.

TABLE IV

Soluble phosphorus (expressed as ppm) from experimental soils in various extractants (At the beginning of the clover experiment)

| Soil | Extractant | No superphosphate | Superphosphate, kg/dunam | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Powder form | | | Ganular form | | |
| | | | 5 | 10 | 15 | 5 | 10 | 15 |
| Hazorea | $H_2O$ | 1.1 | 2.4 | 4.8 | 8.4 | 1.5 | 2.0 | 3.8 |
| | $NaHCO_3$ | 2.6 | 11.9 | 21.5 | 24.8 | 4.1 | 5.7 | 11.7 |
| | $NH_4F$ | 5.1 | 14.3 | 29.1 | 44.6 | 6.5 | 13.7 | 15.7 |
| Degania | $H_2O$ | 1.1 | 2.2 | 4.0 | 5.4 | 1.6 | 1.8 | 4.3 |
| | $NaHCO_3$ | 4.9 | 12.4 | 23.5 | 24.1 | 12.2 | 19.1 | 24.6 |
| | $NH_4F$ | 4.2 | 13.6 | 25.8 | 27.0 | 5.1 | 5.6 | 11.9 |
| Gilat | $H_2O$ | 0.7 | 3.9 | 6.0 | 7.7 | 2.4 | 3.6 | 5.1 |
| | $NaHCO_3$ | 2.5 | 10.9 | 18.7 | 27.6 | 6.4 | 19.9 | 22.9 |
| | $NH_4F$ | 10.4 | 26.6 | 40.4 | 53.3 | 16.5 | 22.2 | 22.6 |
| Rehovot | $H_2O$ | 2.6 | 8.3 | 16.8 | 22.8 | 8.2 | 14.2 | 15.9 |
| | $NaHCO_3$ | 7.2 | 9.3 | 29.2 | 29.4 | 20.5 | 26.3 | 26.8 |
| | $NH_4F$ | 21.0 | 36.0 | 52.1 | 68.3 | 36.8 | 55.6 | 63.5 |

The amounts of phosphorus extracted increase as more superphosphate is added to the soil. However the increase in soluble phosphorus is not proportional to the rate of fertilization. In most soils less phosphorus is extracted from the treatments to which superphosphate was added in granular form than from those to which powder was applied. Analysis of variance showed that the overall differences between treatments are highly significant. Examination of $F$ values showed that the differences between extracted values of phosphorus due to soils and due to fertilizers added are much more significant than the differences due to their interaction. Also, the variation among the treatments that received granular superphosphate is larger than among the treatments which received the powder form.

In the period between the harvest of the clover plants and sowing of corn, soil samples were taken, as already described and soluble phosphorus was determined again by the same extraction methods as described previously. The results are given in Table V. By comparing the results for soluble phosphorus in Table V to those in Table IV it may be seen that the amount of extracted phosphorus was lower in the later sampling for the water and $NH_4F$ extracts. In the case of $NaHCO_3$ extract no clear trend exists. Analysis of

variance of the data relating to soluble soil phosphorus before the corn experiment in general gave results similar to those relating to the tests in the clover experiment.

TABLE V

Soluble phosphorus (expressed as ppm) from experimental soils in various extractants (Before the corn experiment)

| Soil | Extractant | No superphosphate | Superphosphate, kg/dunam | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Powder form | | | Granular form | | |
| | | | 5 | 10 | 15 | 5 | 10 | 15 |
| Hazorea | $H_2O$ | 0.9 | 0.8 | 1.0 | 1.8 | 0.9 | 0.9 | 0.8 |
| | $NaHCO_3$ | 10.1 | 11.1 | 13.2 | 28.3 | 8.6 | 8 7 | 10.2 |
| | $NH_4F$ | 2.3 | 3.9 | 6.1 | 13.5 | 3.1 | 3.5 | 4.2 |
| Degania | $H_2O$ | 0.9 | 1.8 | 2.2 | 2.2 | 0.9 | 1.2 | 1.3 |
| | $NaHCO_3$ | 13.1 | 15.2 | 19.8 | 23.4 | 9.0 | 17.4 | 17.9 |
| | $NH_4F$ | 3.5 | 6.1 | 10.1 | 5.6 | 3.0 | 3.5 | 3.2 |
| Gilat | $H_2O$ | 0.3 | 1.5 | 2.3 | 4.2 | 0.5 | 0.5 | 0.7 |
| | $NaHCO_3$ | 5.7 | 15.7 | 24.9 | 36.3 | 8.8 | 7.1 | 16.0 |
| | $NH_4F$ | 2.3 | 3.4 | 7.5 | 10.8 | 3.3 | 2.8 | 2.9 |
| Rehovot | $H_2O$ | 2.0 | 3.4 | 7.9 | 10.7 | 3.8 | 7.6 | 9.2 |
| | $NaHCO_3$ | 7.2 | 12.7 | 23.1 | 31.3 | 11.4 | 24.8 | 26.8 |
| | $NH_4F$ | 11.6 | 26.1 | 36.1 | 48.9 | 18.7 | 33.2 | 40.7 |

*Correlations between yields and soluble phosphorus*

Correlations were examined between the yields of clover obtained and soil phosphorus extracted. The correlated extracts were made on soil samples taken at the time of the first clover cutting. It was assumed that at that time the reactions between the added phosphates and the soil were nearly in equilibrium. Since the plant growth by the time of the first cutting was small, it is assumed that probably little of the soil phosphorus had been absorbed.

The relations between relative yields of clover and the amount of phosphorus extracted by the three methods used were calculated according to Black [3]. Regressions of *cb* (from the Mitscherlich equation) upon the phosphorus amounts in the three soil extracts were calculated. At first, the calculations were performed on all treatments and soils. However it seemed that the results for the sandy soil from Rehovot differ from the three other soils. Therefore, another calculation was done for the samples of the soils from Hazorea, Degania and Gilat, omitting the treatments on the soil

from Rehovot. The regressions and correlations are given in Table VI. The calculations recorded in this table show that only in the case of the water extract do the samples of Rehovot fit poorly into the regression pattern. For the two other phosphorus extracts the regression was practically unchanged if the samples from Rehovot were omitted. The phosphorus extracted by $NaHCO_3$ solution shows a higher correlation coefficient than that extracted by $NH_4F$ solution.

TABLE VI

Regressions and correlations of *cb* upon soil phosphorus tests

| Experiment | Soil extract | Soil samples | Regression equation | $t$ | $r$ |
|---|---|---|---|---|---|
| Clover experiment | $H_2O$ | All treatments | $y' = 0.071x' + 0.795$ | 3.8** | 0.58** |
| | | Rehovot omitted | $y' = 0.237x' + 0.348$ | 6.6** | 0.82** |
| | $NaHCO_3$ | All treatments | $y' = 0.056x' + 0.320$ | 7.2** | 0.80** |
| | | Rehovot omitted | $y' = 0.059x' + 0.311$ | 6.5** | 0.81** |
| | $NH_4F$ | All treatments | $y' = 0.023x' + 0.591$ | 4.8** | 0.66** |
| | | Rehovot omitted | $y' = 0.032x' + 0.530$ | 4.3** | 0.68** |
| Corn experiment | $H_2O$ | All treatments | $y' = 0.198x' + 1.073$ | 3.7** | 0.59** |
| | | Rehovot omitted | $y' = 0.195x' + 0.928$ | 1.0 | 0.22 |
| | $NaHCO_3$ | All treatments | $y' = 0.015x' + 1.542$ | 1.1 | 0.21 |
| | | Rehovot omitted | $y' = 0.040x' + 0.573$ | 1.9 | 0.39 |
| | $NH_4F$ | All treatments | $y' = 0.048x' + 1.233$ | 4.3** | 0.64** |
| | | Rehovot omitted | $y' = 0.129x' + 0.541$ | 2.5* | 0.50* |

$$t = \frac{\text{regression coefficient}}{\text{standard error of regression coefficient}}$$

$r$ = correlation coefficient

$y' = cb = \log \frac{A}{A - y}$ $\qquad x' = b$ = phosphorus extraction value in P ppm

* significant at 0.05 level

** significant at 0.01 level

Correlations and regressions between phosphorus soluble in the extracts tested, and the content of phosphorus in plants were calculated. They are presented in Table VII. The regressions and correlations calculated for all treatments are not significant, or have a very low significance. However, if the relations are calculated separately for each soil, their significance in general is very high.

Correlations between extracted phosphorus before sowing of corn and corn yields were calculated. For these calculations some assumptions were made. The corn yield was dependent only on the residual phosphorus, whose actual value is unkown. Therefore calculations of the $A$, $b$, $c$ values in the Mitscherlich equation as

TABLE VII

| Soil | Crop residue | Regression equation | $t$ | $r$ |
|---|---|---|---|---|
| | | $y = 2.44x - 62$ | 3* | 1.00 |
| | | $y = 3.32x - 82$ | 4.7** | 1.00** |
| | | $y = 2.69x - 42$ | 1.2* | 1.00** |
| | | $y = 1.46x - 10$ | 0.83** | 1.00** |
| | | $y = 1.12x - 28$ | 1.80* | 1.00* |
| | | $y = 2.35x - 50$ | 2.2** | 1.00* |
| | | $y = 2.91x - 62$ | 1.4** | 1.00** |
| | | $y = 2.36x - 40$ | 2.5* | 1.00 |
| | | $y = 1.29x - 29$ | 2.0** | 1.00* |
| | | $y = 2.56x - 19$ | 2.40 | 1.00* |
| | | $y = 2.14x - 62$ | 1.80 | 1.00 |
| | | $y = 2.58x - 64$ | 1.80** | 1.00** |
| | | $y = 2.39x - 42$ | 1.00** | 1.00** |
| | | $y = 2.21x - 11$ | 4.70** | 1.00** |
| | | $y = 2.33x - 13$ | 4.10** | 1.00** |

$t = \frac{\text{regression coefficient}}{\text{standard error of regression coefficient}}$

$r$ = correlation coefficient

* significant at 0.05 level

** significant at 0.01 level

## *Laboratory experiments*

In order to study whether there are differences between the tested soils in their phosphorus fixing capacity they were mixed in a dry state with various amounts of superphosphate. The mixtures were prepared so as to receive from 20 to 240 ppm $P_2O_5$ on a weight basis and then wetted to the field capacity for moisture for the pot experiments. Samples were taken from the mixture at various

times, and water-soluble phosphorus was determined. The results are presented in Table VIII. They are means from three replicates. The variation between replicates was very small and no statistical analysis is presented.

TABLE VIII

Water-soluble phosphorus in soil samples mixed with various amounts of superphosphate at various times after addition (calculated on oven-dry soil)

| Soil | Amount of P added ppm | Soluble P in samples, ppm | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Immediately after mixing | After 1 day | After 1 week | After 2 weeks | After 4 weeks | After 10 weeks | After 40 weeks |
| Hazorea | 0 | 3.4 | 2.2 | 1.2 | 0.5 | 0.5 | 0.5 | 0.6 |
| | 20 | 5.8 | 2.6 | | | 1.8 | | |
| | 40 | 9.0 | 6.2 | | | 2.7 | | |
| | 60 | 12.9 | 6.9 | | | 3.6 | | |
| | 80 | 23.4 | 14.0 | 11.4 | 7.0 | 4.8 | 4.7 | 3.7 |
| | 120 | 38.1 | 19.2 | | | 6.0 | | |
| | 240 | 57.3 | 33.5 | | | 7.0 | | |
| Degania | 0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| | 20 | 4.0 | 2.4 | | | 1.6 | | |
| | 40 | 7.9 | 4.9 | | | 2.0 | | |
| | 60 | 9.1 | 7.4 | | | 2.8 | | |
| | 80 | 21.7 | 15.0 | 9.9 | 7.4 | 4.3 | 3.3 | 2.9 |
| | 120 | 29.3 | 17.6 | | | 5.1 | | |
| | 240 | 46.3 | 39.5 | | | 7.7 | | |
| Gilat | 0 | 1.2 | 1.0 | 0.5 | 0.5 | 0.3 | 0.2 | 0.4 |
| | 20 | 5,6 | 3.3 | | | 1.8 | | |
| | 40 | 8.5 | 7.9 | | | 3.3 | | |
| | 60 | 10.6 | 8.7 | | | 6.7 | | |
| | 80 | 20.0 | 15.2 | 12.9 | 10.4 | 7.2 | 4.2 | 4.0 |
| | 120 | 37.3 | 25.9 | | | 9.0 | | |
| | 240 | 61.2 | 55.5 | | | 10.9 | | |
| Rehovot | 0 | 3.5 | 3.0 | 2.3 | 1.6 | 1.5 | 1.5 | 1.7 |
| | 20 | 18.9 | 12.1 | | | 10.0 | | |
| | 40 | 34.5 | 23.4 | | | 14.9 | | |
| | 60 | 43.0 | 33.9 | | | 23.8 | | |
| | 80 | 60.7 | 41.2 | 34.8 | 32.0 | 28.7 | 26.2 | 9.3 |
| | 120 | 83.5 | 68.0 | | | 48.2 | | |
| | 240 | 190.0 | 135.0 | | | 100.5 | | |

As may be seen from Table VIII, in all cases there is a definite decrease of solubility of phosphate with time, this decrease being independent of the amount added. In all cases a very small percentage of the phosphate added is left in a water-soluble state after 4 weeks of contact with wet soil. Only in the coarse-textured soil

from Rehovot is a substantial (approximately less than 50 per cent of the amount added) part of the phosphate found in a water-soluble form after 4 weeks.

In addition to water extracts, phosphorus soluble in a sodium bicarbonate solution [16] was determined on the above described soil-superphosphate mixture. The results are given in Table IX. In this case almost all the added phosphate is extracted, if the extraction was performed immediately after mixing. The percentage of recovery of soluble phosphates after 4 or 10 weeks, however, is relatively small.

TABLE IX

Phosphorus soluble in $NaHCO_3$ solution in soil samples mixed with various amounts of superphosphate at various times after adding (calculated on oven-dry soil)

| Soil | Amount of P added, ppm | Soluble P in samples, ppm | | | | | |
|---|---|---|---|---|---|---|---|
| | | Immediately after mixing | After 1 week | After 2 weeks | After 4 weeks | After 10 weeks | After 40 weeks |
| Hazorea | 0 | 14.2 | 6.5 | 4.4 | 2.3 | 2.3 | |
| | 20 | 26.7 | | | | | |
| | 40 | 38.4 | | | | | |
| | 60 | 62.4 | | | | | |
| | 80 | 83.3 | 40.0 | 31.2 | 10.4 | 9.6 | 9.0 |
| Degania | 0 | 10.0 | 8.8 | 7.5 | 4.8 | 3.9 | |
| | 20 | 30.6 | | | | | |
| | 40 | 44.1 | | | | | |
| | 60 | 68.0 | | | | | |
| | 80 | 87.7 | 48.2 | 42.3 | 17.9 | 7.1 | 6.4 |
| Gilat | 0 | 6.1 | 5.5 | 4.0 | 2.2 | 2.2 | |
| | 20 | 24.2 | | | | | |
| | 40 | 42.2 | | | | | |
| | 60 | 67.1 | | | | | |
| | 80 | 82.1 | 47.7 | 42.0 | 17.9 | 11.2 | 9.3 |
| Rehovot | 0 | 13.3 | 11.1 | 9.6 | 4.9 | 2.1 | |
| | 20 | 34.2 | | | | | |
| | 40 | 50.3 | | | | | |
| | 60 | 70.6 | | | | | |
| | 80 | 88.7 | 62.8 | 51.3 | 27.9 | 15.2 | 16.4 |

## DISCUSSION AND CONCLUSIONS

### *Granular versus powder superphosphate*

The purpose of this investigation was to compare under similar

conditions the effeciency of granular versus powder superphosphate. By comparing fertilizer response curves it is possible to draw conclusions in this respect. The compared value is "$c$" of the Mitscherlich equation. As the value of $c$ is increased, the response curve becomes steeper, and accordingly larger yields are obtained for the same amount of fertilizer applied. The relation between values of $c$ and the amounts of fertilizer required to obtain the same yield is inversely proportional. This statement is true only if the $A$ values corresponding to the $c$'s in the two response curves compared are identical.

This proportion may be shown mathematically as follows: Let $y_0$ be the yield obtained without fertilizer and $y_1$ the yield obtained by addition of some amount of fertilizer. Let $x_0$ be no fertilizer addition and $x_1$ the amount needed to produce the yield $y_1$. One form of fertilizer is represented by $c'x'$ and the other by $c''x''$.

Then:

$$\log (A - y_0) = \log A - c'x_0' = \log A - c''x_0''$$
$$\log (A - y_1) = \log A - c'x_1' = \log A - c''x_1''$$

The above equations are true as the assumptions were made that $A$ is identical for the two forms of fertilizers. The yield $y_0$ where no fertilizer was added is the same for both cases (two different forms of fertilizers) and the same is true for $y_1$ according to the previous statement. Accordingly for any value of $x$: $c'x' = c''x''$ or $c'/c'' = x''/x'$. This relation is not altered by introducing the values of $b'$ and $b''$ into the equations.

In the situation where the $A$ values as expressed by the measured yield are not identical, it is possible to calculate relative yields, where $A$ has been assigned the value of 100. The constant $c$ is not altered by this transformation. This operation seems justified in cases where the maximum obtainable yields are reasonably like for the two different forms of fertilizers. Thus, according to the above explanation, comparison of $c$ values may show the relative efficiency of fertilizer forms.

By comparing the yield response equations in Fig. 1 we may see that in two cases, in the soils from Hazorea and Gilat, the $c$ values for the powder form of superphosphate are higher than for the granular form. Accordingly the powder superphosphate acts more efficiently, especially at lower levels of fertilizer application.

The reverse is true for the soils from Degania and Rehovot. However the comparison of values of *c* for the soil from Degania is not valid as the yields obtained by the granular fertilizer are much lower than those obtained by the powder.

Actually only in one soil, that from Rehovot, was the granular superphosphate more efficient than the powder form. On the other hand the laboratory experiments (Table VIII) showed that in the soil from Rehovot a great part of the added superphosphate remains in water-soluble form and therefore is probably available to plants.

The results of this work together with the results obtained by other authors [19] indicate that no yield increases in the soils tested should be expected from use of the granulated form of superphosphate under most conditions. However, it should be noted that under field conditions, where technical aspects of fertilizer usage are concerned, factors such as feasibility for drill application, wind dispersion etc. favour the granular form. Because of the last reason and because of the inherent limits of a greenhouse experiment, no final conclusions relating to the economic value of granulated superphosphate in practical agriculture, may be drawn from this investigation.

*Correlation of soil tests and plant yields*

It would also be of interest to compare the correlations and regressions of crop yields on the various soil tests for soluble phosphorus. It is clear that these correlations are not of general value as they cannot be used as clues for fertilizer responses in the field. With this limitation in mind, the correlations can be used, however, for similar pot experiments and as indications for future field trials.

Black [3] showed that instead of the value of *cb* in the original Mitscherlich equation the regression coefficient may be inserted as *c*, and the soil phosphorus test value as *b*. This would be true if the regression value would pass the zero point in the coordinate system. However, in all cases in this work, the regression line crossed the *y* axis at some point above zero (Table VI). Therefore the whole right side of the regression equation should be inserted instead of *cb* in the Mitscherlich equation.

In the clover experiment the best correlation between soil test and yield increase were obtained for the $NaHCO_3$ extract, and its

regression will be used for illustration. From Fig. 1 the equation for the fertilizer response curve for the soil from Hazorea is taken:

$$\log (73.7 - y) = \log 73.7 - 0.11 (x + 3.0)$$

The altered equation will read:

$$\log (73.7 - y) = \log 73.7 - (0.11 + c_1 b)$$

Inserting the regression equation for $NaHCO_3$ extract from Table VI we obtain

$$\log (73.7 - y) = \log 73.7 - (0.11x + 0.056b + 0.320)$$

At first sight this equation seems slightly paradoxical, as it shows that some yield will be obtained without addition of fertilizer and even if the soil test used shows zero phosphorus. However, there is no paradox, as it should be borne in mind that the amount of extracted phosphorus is not identical to the phosphorus available to plants; it serves only as an indication. The written equation shows that actually the $NaHCO_3$ method does not extract the whole available phosphorus in soil.

*Yield of phosphorus in clover plants*

On first examination, the relation between content of phosphorus in plants and the amount of phosphorus extracted in the soil tests appears to be proportional. If this form of relation would be true it would indicate that under conditions of an infinitely large supply of phosphorus in soil, the plants would accumulate infinite amounts of it. It seems quite obvious that such relations cannot be expected. The other alternative is, that the phosphorus content curve is exponential, but under our conditions values were obtained, which permitted the drawing of only the lower part of the exponential curve, *i.e.* the approximately linear portion. If this assumption is correct it would indicate that the phosphorus contents obtained were far from the maximal possible values.

It is strikking, that the low-yielding plants in soil from Rehovot contained relatively high percentages of phosphorus. This indicates that the supply of phosphorus was sufficient for much higher plant yields than were actually obtained and that there were other limiting factors.

The conclusion that might be drawn is that as long as there are other limiting factors, the supply of phosphorus would suffice, but by raising the general potential for higher yields, more phosphorus

would be necessary for maximal yields. Under the new conditions the correlations found between soil test and yield would not be valuable and new relations should be sought.

The laboratory experiments show that fixation of superphosphate phosphorus, which is initially water soluble, as measured by solubility in water and in $NaHCO_3$ is relatively high in three of the soils tested. The fourth, the soil from Rehovot, a coarse-textured soil, has a much lower fixing capacity, than the other soils. In this case it is quite obvious that the sand fraction, which is its main constituent, does not provide a fixation mechanism. However, the crop yields obtained show, that the measured fixation does not influence appreciably the fertilizer phosphorus availability. In most cases in spite of this fixation, the response to fertilization was high in the first crop and even in the second.

## SUMMARY

The efficiency of superphosphate in granular and powder form was compared in four typical Israeli agricultural soils in a greenhouse investigation. Under greenhouse conditions no advantage was found for the granular form either in the first crop (clover) or in the second following crop (corn). The efficiency of superphosphate forms was evaluated from Mitscherlich yield curves by comparing the constants which determine the slopes of the curves (*c*).

Soil samples were taken from the pots and soluble phosphorus in three different extractions was related to the relative yields obtained. The $NH_4F$ extract gave a fairly good correlation for both crops tested and all experimental soils included. The $NaHCO_3$ extract gave a good correlation for the clover crop.

Phosphorus was determined in the clover plants and the amount of phosphorus extracted by plants was related to soil tests. Generally, very good correlations were obtained if they were calculated individually for each soil.

Laboratory experiments showed that the added water-soluble phosphorus is relatively quickly fixed into insoluble forms (in water and $NaHCO_3$ solution) in three out of four soils. In the fourth, a coarse-textured soil, the fixation power is relatively low.

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# THE DETERMINATION OF ALUMINIUM IN SOIL, ASH AND PLANT MATERIALS USING ERIOCHROME CYANINE R.A.

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## INTRODUCTION

In carrying out investigations into the nutrient status of plants grown on "fly ash", the waste product of power stations burning pulverised fuel, it was found that a major part of the problem was concerned with the high available-aluminium content of the ash, [8 9 11] as revealed in extracts made in Morgan's Universal Extracting Reagent (sodium-acetate acetic-acid buffer, pH 4·8) [6].

As the ash proved highly toxic to some plants, in most cases only small amounts of plant material were available for analysis. It was therefore necessary to find a rapid method of estimating aluminium in small quantities of plant materials, as well as in ash and soils.

The determination of aluminium by the "Aluminon" method has been described by several workers, and in plant and soil materials notably by Chenery [2 3] and Robertson [10], both of whom used thioglycollic acid as an inhibitor for the interference caused by iron, thus eliminating tedious separations. In spite of this improvement, however, the method is time consuming and requires very strict control of experimental conditions in order to obtain reproducible results.

Recently, a method for determining aluminium in iron ore, using stabilised Eriochrome Cyanine R. was described by Hill [4]. This paper describes an adaptation of Hill's method for use on plant and soil extracts which has proved to be reliable and rapid for the estimation of microgram quantities of aluminium with an accuracy

of $\pm$ 0·5 $\mu$g and whose sensitivity allows the use of smaller samples than are necessary with other methods.

## PREPARATION OF SAMPLES

1. *Plant material*

A wet-ashing method using nitric, perchloric and sulphuric acids is employed as described by Piper [7]. The high acidity of the final plant extract, however, caused considerable difficulty and to obviate this the sulphuric acid used is reduced to the minimum consistent with safety.

1-g samples of oven-dried, ground material are oxidised with 20 ml of concentrated nitric acid, 4 ml of perchloric acid and 0·5 ml of concentrated sulphuric acid.

After ashing, the samples are cooled, diluted to about 70 ml, and transferred to beakers where they are adjusted to pH 3 with dilute (4 : 1) ammonia using the glass electrode. The pH should not be raised above 3 at this stage in order to avoid any possibility of precipitation of aluminium as the hydroxide [12].

The solutions are then transferred to 100-ml graduated flasks and made up to the mark with distilled water. 10-ml aliquots are taken for determination.

2. *Soil and ash*

The samples are air dried and passed through a 2-mm mesh sieve. 10 g of the dried and sieved material are taken and shaken with 100 ml of Morgan's Extracting Reagent for six hours on the end-over-end shaker.

The solid material is filtered off and the filtrate retained for analysis. In many cases further dilution of the filtrate is necessary in order to bring the aluminium concentration within the range of the reagent (0 — 20 $\mu$g). 5-ml aliquots are taken for determination.

## REAGENTS

1. *Morgan's Universal Extracting Reagent* [6]

100 grams of AnalaR sodium acetate are dissolved in about 800 ml of distilled water, 30 ml of glacial acetic acid are added and the solution is made up to 1 litre.

2. *Eriochrome Cyanine R. 0·075%* [4]

0·75 grams of Erichrome Cyanine R. are dissolved in about 200 ml of distilled water, 25 grams each of sodium chloride and ammonium nitrate are added, followed by 2 ml concentrated nitric acid. The solution is diluted to 1 litre and mixed.

3. *Iron-compensating solution. 100 ppm*

0·7022 grams of AnalaR ferrous ammonium sulphate are dissolved in about 100 ml of distilled water and 5 ml conc. sulphuric acid in a silica basin. 5 ml of conc. nitric acid are added to oxidise ferrous iron to ferric. The solution is warmed to expel oxides of nitrogen, and when cool is transferred to a 1-litre graduated flask and made up to the mark [7].

4. *Sodium thioglycollate 0·5%*

2·5 grams of sodium thioglycollate are dissolved in 200 ml of water, 125 ml of 95% ethyl alcohol are added and the solution made up to 500 ml. This solution must be prepared afresh each day.

5. *Ammonium-acetate buffer, pH 6·0* [4]

320 grams of AnalaR ammonium acetate are dissolved in sufficient water, 5 ml of glacial acetic acid are added and the solution diluted to 1 litre.

6. *Standard aluminium solution* [10]

0·1759 grams of potassium alum, $AlK(SO_4)_2.12H_2O$ are dissolved in distilled water and made up to 1 litre in a graduated flask. This solution contains 10 ppm aluminium.

## PROCEDURE

A 10- or 5-ml sample prepared as described is pipetted into a 50-ml graduated flask. 2 ml of iron-compensating solution and 10 ml of sodium thioglycollate solution are added, followed by 5 ml of the Eriochrome Cyanine reagent. The solution is mixed thoroughly by swirling and 10 ml of ammonium acetate buffer (pH 6) are added. The contents of the flask are made up to the mark and again thoroughly mixed.

The absorption is read after 18 minutes either on the Unicam Spectrophotometer at 535 mμ in the 1-cm cells, or on the E.E.L. Long Cell Absorptiometer, using the 1-cm cells and filter 604.

The colour reaches its maximum intensity after about 10 minutes and is stable for a further 30 minutes.

A blank is prepared as above but omitting the sample, and this is used to zero the instrument.

A calibration curve is prepared using standard aluminium solutions.

## DISCUSSION

The method of Hill [4] is followed with a few modifications. These are firstly, the omission of the versenate blank, secondly a reduction in the amount of thioglycollate used and thirdly an increase in the volume of buffer solution added. The use of an iron blank is elaborated and the effects of pH and time are discussed.

Hill [4] used a versenate blank to compensate for interference caused by vanadium, beryllium and zirconium, but as these elements are not normally present in interfering quantities, this may be omitted without introducing any error. It was found that the iron/sodium thioglycollate blanks did not vary appreciably when read against distilled water, and these were used to zero the instruments.

A most important point, on which Hill's paper is inconsistent, is that of the order in which the reagents are added. The eriochrome cyanine-aluminium complex forms rapidly in slightly acid solutions, but more slowly at pH 6 [5], and the colour-forming reagent must therefore be added before the ammonium-acetate buffer. In cases where this order was reversed, the authors found that the colour development was retarded and low readings were obtained.

Although the complex is formed at lower pH values, the samples must be adjusted to pH 6 before readings are taken, as the eriochrome reagent itself has a high absorption at 535 m$\mu$ if the pH is below this value. At pH 6, the reagent background colour is minimal as compared with the aluminium complex. Thus even slight variations of pH lead to large errors in the estimation. The pH of each sample was tested after determination and those not falling between pH 5·9 and 6·1 were rejected. It was found that this only occurred if acid extracts were used, and provided that the plant extracts were brought to pH 3 before making up, the ammonium-acetate buffer always proved effective.

The use of thioglycollic acid as an iron-inhibitor is described by Chenery [2] for use with the "Aluminon" method at pH 3–4, when it forms a colourless complex with iron. Hill [4] uses sodium thioglycollate for the same purpose in the eriochrome cyanine method at pH 6, but here it was found that at this pH the purple iron-thioglycollic complex which is used as a colourimetric test for iron, and which forms at pH 7 [1] was beginning to appear.

Recovery experiments using different levels of added iron showed that a maximum level of interference is reached when 100 $\mu$g of iron are present. In Table I is shown the effect of varying amounts

TABLE I

| Effect of added iron | | | |
|---|---|---|---|
| Aluminium added, $\mu$g | Iron added, $\mu$g | Aluminium found, $\mu$g | Difference using Fe blank |
| 0 | 0 | 0 | |
| 0 | 1000 | 2·0 | 0·0 |
| 5 | 0 | 5·4 | |
| 5 | 10 | 5·6 | |
| 5 | 25 | 6·0 | |
| 5 | 50 | 6·3 | |
| 5 | 75 | 6·4 | |
| 5 | 100 | 6·8 | 4·8 |
| 5 | 1000 | 6·8 | 4·8 |
| 0 | 100 | 2·0 | 0·0 |
| 2·5 | 100 | 4·3 | 2·3 |
| 5·0 | 100 | 6·4 | 4·4 |
| 7·5 | 100 | 9·2 | 7·2 |
| 10·0 | 100 | 11·5 | 9·5 |

of iron on the recovery of aluminium from standard solutions. The first two columns give respectively the amounts of aluminium and iron added to each solution, while in column three is shown the recovery of aluminium obtained without account being taken of the iron present. It will be seen that the recoveries increase with iron added until the latter reaches the 100-$\mu$g level, after which the interference remains constant. The fourth column indicates the aluminium found in the presence of 100 $\mu$g or more of iron when compared with an iron blank, and in this case the recoveries from solutions containing 100 $\mu$g of iron agree with the amounts of aluminium added.

It was therefore found possible to compensate for this interference by the addition of an amount of iron exceeding 100 $\mu$g, and for this purpose the addition of 2 ml of a 100-ppm iron-compensating solution gave reliable recoveries of aluminium from standard solutions.

*Effect of thioglycollate*

The amount of thioglycollic acid used by Chenery [2] to inhibit iron is 1 ml of 1% for a 25-ml sample, whereas Hill [4] uses 25 ml of 0·3% thioglycollate in his iron-ore samples. It was not anticipated that the level of iron in plants would exceed the 500-ppm level in the oven-dry material and would thus be less than 50 $\mu$g in the samples.

It was thought possible therefore that the amount of thioglycollate used could be reduced, although the alcohol content of the final solution was not changed.

The effect of various levels of sodium thioglycollate on the recovery of aluminium in the presence and absence of iron is shown in Table II.

TABLE II

The effect of various levels of sodium thioglycollate on the interference due to iron

| Aluminium added, $\mu$g | Iron added, $\mu$g | Thioglycollate added | Aluminium found, $\mu$g |
|---|---|---|---|
| 0·0 | 0·0 | 1 ml 0·5% | 0·0 |
| 5·0 | 0·0 | 1 ml 0·5% | 4·6 |
| 0·0 | 50·0 | 1 ml 0·5% | 0·4 |
| 5·0 | 50·0 | 1 ml 0·5% | 5·6 |
| 0·0 | 0·0 | 5 ml 0·5% | 0·0 |
| 5·0 | 0·0 | 5 ml 0·5% | 5·2 |
| 0·0 | 50·0 | 5 ml 0·5% | 0·3 |
| 5·0 | 50·0 | 5 ml 0·5% | 5·6 |
| 0·0 | 0·0 | 10 ml 0·5% | 0·0 |
| 5·0 | 0·0 | 10 ml 0·5% | 5·1 |
| 0·0 | 50·0 | 10 ml 0·5% | 0·6 |
| 5·0 | 50·0 | 10 ml 0·5% | 6·2 |
| 0·0 | 0·0 | 15 ml 0·5% | 0·0 |
| 5·0 | 0·0 | 15 ml 0·5% | 4·6 |
| 0·0 | 50·0 | 15 ml 0·5% | 1·2 |
| 5·0 | 50·0 | 15 ml 0·5% | 6·1 |
| 0·0 | 0·0 | 25 ml 0·3% | 0·0 |
| 5·0 | 0·0 | 25 ml 0·3% | 4·8 |
| 0·0 | 50·0 | 25 ml 0·3% | 1·6 |
| 5·0 | 50·0 | 25 ml 0·3% | 5·9 |

It will be seen that as little as 1 ml of 0·5% sodium thioglycollate was sufficient to inhibit the iron interference. However, since the method is also used for determinations of aluminium in soil and ash samples where the iron content is likely to be higher, it was thought inadvisable to reduce the thioglycollate to this low level, and a final quantity of 10 ml of 0·5% was adopted.

*Effect of time*

It was observed that unless the reaction was carried out in acid conditions, there was an appreciable time-lag before the complex reached its full intensity [5]. Investigations into the time required for the colour to be formed were extended to establish the period over which the complex is stable. It was found that the maximum absorbance was obtained after 8 minutes and remained constant for a further 30 minutes, after which it began to fade, as shown in Table III.

TABLE III

Effect of time on colour intensity

| Time in minutes from addition of reagent | E.E.L. reading | Time in minutes from addition of reagent | E.E.L. reading |
|---|---|---|---|
| 2 | 13·2 | 10 | 15·0 |
| 3 | 13·8 | 15 | 15·0 |
| 4 | 14·2 | 20 | 15·0 |
| 5 | 14·5 | 25 | 15·0 |
| 6 | 14·9 | 30 | 15·0 |
| 7 | 14·9 | 40 | 15·0 |
| 8 | 15·0 | 50 | 14·9 |
| 9 | 15·0 | 60 | 14·7 |

*Sensitivity compared with standard "Aluminon" method*

Eriochrome Cyanine proved to be about twice as sensitive as the standard "Aluminon" method used by Chenery [2 3].

Figure 1 shows the calibration curves for each method using the E.E.L. Long Cell Absorptiometer. In the Eriochrome method the samples were made up to 50 ml and were read in the 1-cm cells (Filter 604) while in the Aluminon method the samples were made up to 25 ml and read in the 0·5-cm cells. It is not practicable to use longer cells as the reagent background colour in the blank then makes it impossible to zero the instrument.

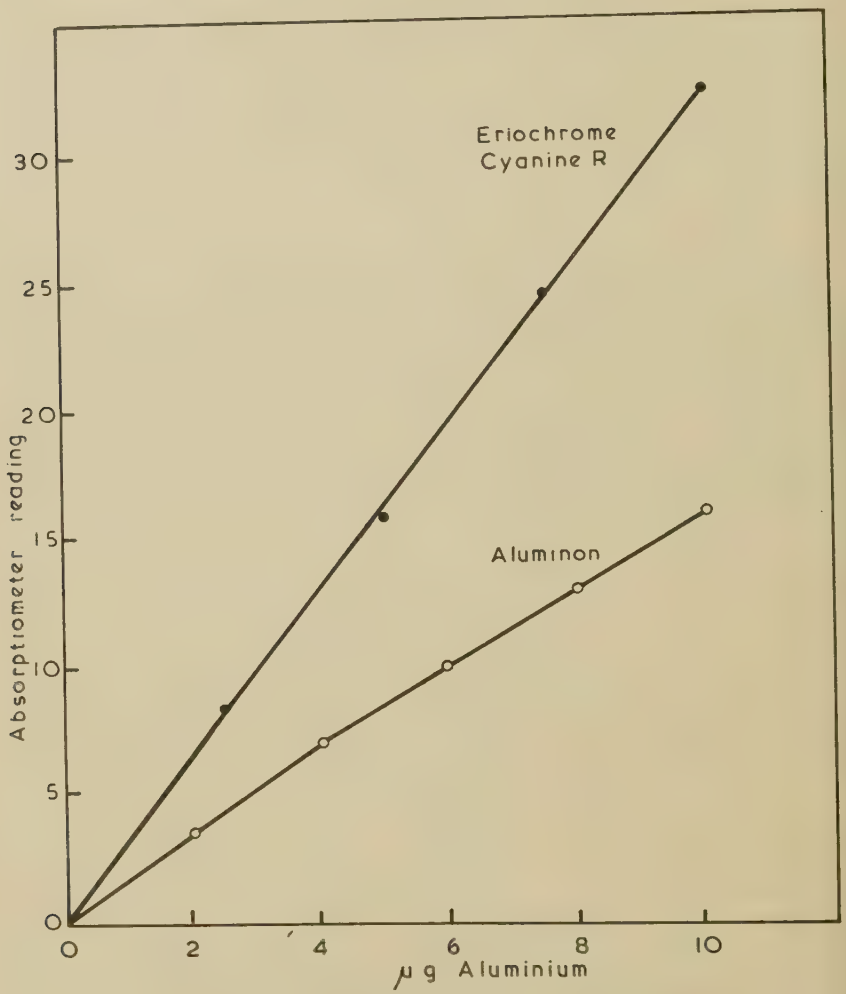


Fig. 1. Calibration curves for the determination of aluminium by Eriochrome Cyanine R. and Aluminon. E.E.L. long-cell absorptiometer. Filter 604.

*Recovery from plant material*

Determinations of aluminium in extracts of brussels-sprouts leaves grown on fly-ash were made, and known amounts of aluminium added to the solutions were recovered as shown in Table IV. In this instance 0·2 grams of the plant material were dissolved in 3·0 ml of conc. sulphuric acid and made up to 100 ml. The acid extract

was neutralised as described and 20-ml aliquots were taken for analysis.

TABLE IV

| Aluminium added, μg | Aluminium found, μg | Recovery % |
|---|---|---|
| 0·0 | 1·8 | |
| 5·0 | 6·7 | 98·5 |
| 10·0 | 12·3 | 104·3 |
| 15·0 | 17·3 | 103·0 |

Because of the small amounts of aluminium present in extracts of this dilution, more plant material was used in the later experiments as described below.

Comparison with determinations made by the "Aluminon" method show very good agreement, and in Table V are shown the results of analyses made by the two methods on an extract of leaves of *Atriplex hastata*, var. *deltoidea* grown on fly-ash. In this case 1 gram of the material was wet ashed by the nitric-perchloric-sulphuric technique described earlier.

TABLE V

| Aluminium added, μg | Eriochrome method | | Aluminon method | |
|---|---|---|---|---|
| | Aluminium found, μg | Recovery % | Aluminium found, μg | Recovery % |
| 0·0 | 5·45 * | | 5·50 * | |
| 2·0 | 7·55 | 101·0 | 7·80 | 104·0 |
| 5·0 | 11·06 | 105·5 | 10·75 | 102·5 |
| 10·0 | 15·64 | 101·3 | 15·10 | 97·5 |

* Aluminium content of leaves = 55·0 ppm.

*Recovery from fly-ash extracts*

Complete recovery of aluminium added at various levels to fly-ash extract was obtained as shown in Table VI. The extract

TABLE VI

| Sample | Aluminium added, μg | Aluminium found, μg | Recovery % |
|---|---|---|---|
| 5 ml of ash extract diluted 1/100 | 0·0 | 5·6 * | — |
| | 2·5 | 7·4 | 91·5 |
| | 5·0 | 10·5 | 99·0 |
| | 7·5 | 13·0 | 100·7 |
| | 10·0 | 16·2 | 96·5 |
| | 20·0 | 23·8 | 93·0 |

* Aluminium content of ash extract = 112 ppm (= 1120 ppm ash).

was made in Morgan's reagent as described previously and was diluted a further 100 times with distilled water. 5-ml aliquots were taken for analysis.

*Comparison of the aluminium content of ash and soil extracts as given by the Eriochrome and Aluminon methods*

The test samples consisted of: —

1. Fly ash from Hams Hall Power Station.
2. Ordinary garden soil (top 3 inches)
3. Neglected agricultural soil (unlimed, no fertiliser)
4. Podsol from Sutton Park (sample from A 1 horizon)
5. Calcareous soil from Wenlock.

The Morgan's extracts were diluted with distilled water in order to bring the aluminium concentration within the range of the reagents, a trial run being necessary to determine the degree of dilution required.

The aluminium levels found by the two methods are given below in Table VII.

It will be observed from this that there is a close agreement between the results obtained by the two methods except in the case of the ash extracts, where results obtained using Aluminon always exceed the Eriochrome values. It is thought possible that this discrepancy may be attributed to the presence of titanium and the rare earths, which would interfere with the Aluminon determinations by increasing the colour. Up to 0·01 mg of $TiO_2$ per 100 ml can be tolerated [11], and this is equivalent to only 1·5 $\mu$g of Ti in 25 ml. The eriochrome cyanine complex is unaffected by titanium.

It will be noted that this interference was not found when plant material was used, where titanium is not expected to be present except in minute traces. On the other hand it is known that this element constitutes up to 1% of the total ash material as $TiO_2$ (Central Electricity Authority analysis), although the proportion of this extracted by Morgan's Reagent has not been ascertained.

The titanium status of power-station ash is being more fully investigated and further details will appear elsewhere.

TABLE VII

| Sample | Eriochrome method | | | | Aluminon method | | | |
|---|---|---|---|---|---|---|---|---|
| | Dilution of 10% extract | Volume taken, ml | Aluminium found | | Dilution of 10% extract | Volume taken, ml | Aluminium found | |
| | | | μg | ppm | | | μg | ppm |
| 1 | 500× | 5 | 9·35 | 935 | 1000× | 5 | 7·10 | 1420 |
| | | | 9·30 | 930 | | | 6·70 | 1340 |
| | | | 9·00 | 900 | | | 7·65 | 1350 |
| | | | 9·15 | 915 | | | 6·90 | 1380 |
| 1 | 1000× | 5 | 4·40 | 880 | | | | |
| | | | 4·60 | 920 | | | | |
| 2 | 5× | 5 | 3·5 | 35·0 | 5× | 5 | 3·05 | 30·5 |
| | | | 3·35 | 33·5 | | | 2·85 | 28·5 |
| | | | 3·55 | 35·5 | | | 2·85 | 28·5 |
| | | | 3·40 | 34·0 | | | 2·90 | 29·0 |
| | | | 3·10 | 31·0 | | | | |
| | | | 3·25 | 32·5 | | | | |
| 3 | 10× | 2·5 | 4·4 | 176 | 10× | 5 | 8·95 | 179 |
| | | | 4·3 | 172 | | | 8·70 | 174 |
| | | 5 | 8·4 | 168 | | | | |
| | | | 8·45 | 169 | | | | |
| 4 | 5× | 5 | 4·30 | 43·0 | 10× | 5 | 2·35 | 47 |
| | | | 3·95 | 39·5 | | | 2·25 | 45 |
| | | 10 | 7·70 | 38·5 | | | | |
| | | | 7·90 | 39·5 | | | | |
| | | | 8·20 | 41·0 | | | | |
| | | | 8·05 | 40·0 | | | | |
| 5 | 10× | 5 | 1·6 | 32·0 | 10× | 5 | 1·75 | 35 |
| | | | 1·8 | 36 | | | 1·75 | 35 |
| | 5× | 10 | 6·8 | 34 | | | | |
| | | | 6·8 | 34 | | | | |

SUMMARY

A method for the determination of microgram quantities of aluminium using Eriochrome Cyanine R. has been modified for use with plant and soil extracts. The effects of pH, time, and order of addition of the reagents are clarified, and the use of an iron blank in conjunction with sodium thioglycollate as an iron inhibitor is elaborated.

In addition to being rapid and reliable, the method is approximately twice as sensitive as the standard "Aluminon" method.

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# DIE PROBLEMATIK DER BODENVERDÜNNUNG DURCH SAND BEI DER PFLANZENPHYSIOLOGISCHEN GEFÄSSMETHODE ZUR BESTIMMUNG DES IM BODEN VORHANDENEN PFLANZENAUFNEHMBAREN NÄHRSTOFFVORRATES

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## EINLEITUNG

Die pflanzenphysiologische Bodenuntersuchung nach *Mitscherlich* basiert auf den Erkenntnissen des „Wirkungsgesetzes der Wachstumsfaktoren". Aus dem „Wirkungsgesetz" lassen sich die Gesetzmäßigkeiten direkt ableiten, die für die Auswertung der pflanzenphysiologischen Bodenuntersuchung maßgebend sind.

Schon im Jahre 1921 [4] waren die Grundlagen für die pflanzenphysiologische Bodenuntersuchung soweit geschaffen, daß mit ihrer Hilfe wertvolle Düngungshinweise für die praktische Landwirtschaft gegeben werden konnten. Mitscherlich hatte bis dahin festgestellt, daß 1. alle Kulturpflanzen die gleichen Bedingungen an die Düngung stellen und 2. daß der Wirkungswert sowohl im Feld- als auch im Gefäßversuch der gleiche ist. Die Gefäße wurden vollständig mit dem zu untersuchenden Boden gefüllt und dann bei der Umrechnung auf dz/ha die Bodentiefe der Probeentnahme berücksichtigt.

Bereits zwei Jahre später – 1923 – wurden dann von Mitscherlich [5] die ersten Versuche mit „Bodenverdünnungen" durchgeführt. Der Grundgedanke für eine „Bodenverdünnung" mag darin zu suchen sein, daß 1. dadurch der Nährstoffgehalt „schärfer" festgestellt werden kann, 2. daß bestimmte Bodenarten im Gefäßversuch zum Dichtschlämmen neigen, wodurch Ertragsdepressionen auftreten können, die die Bestimmung verfälschen, 3. ist es auch eine Transportfrage, ob zur pflanzenphysiologischen Bodenuntersuchung an die Untersuchungsstationen für einen Boden anstatt 50 kg nur 25 kg oder vielleicht noch weniger abgeschickt werden müssen und 4. endlich ließ sich der Nährstoffvorrat des gewachsenen Bodens – den man ja nicht durch den Felddüngungsversuch, sondern ausschließlich durch den Gefäßdüngungsversuch zu ermitteln vermag – für einen längeren Zeitraum

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feststellen, je mehr man den Boden mit Sand vermengte und je geringer damit die zur Bodenuntersuchung herangezogene Höhe der Bodenschicht des Krumenbodens ist.

Mitscherlich ermittelte zunächst den Nährstoffvorrat eines Grubensandes an Kali und Phosphorsäure und mischte dann gewachsenen Boden in verschiedenen Anteilen hinzu. Die Mischungsverhältnisse und die aus den Erträgen jeweils im Boden festgestellten Nährstoffmengen, die wir als *b*-Werte bezeichnen, sind wiedergegeben in Tabelle I.

TABELLE I

| Gemisch Sand + Boden | Aufnehmbare Kalimengen *b* in dz/ha im Ganzen = im Sande + Boden | |
|---|---|---|
| *Boden I* | | |
| 6,0 kg + 0 kg | 0,193 = 0,193 | + 0,0 |
| 5,5 „ + 0,5 „ | 0,305 = 0,177 | + 0,128 |
| 5,0 „ + 1,0 „ | 0,417 = 0,161 | + 0,256 |
| 4,0 „ + 2,0 „ | 0,641 = 0,129 | + 0,512 |
| *Boden II* | | |
| 6,0 kg + 0 kg | 0,193 = 0,193 | + 0,0 |
| 5,5 „ + 0,5 „ | 0,450 = 0,177 | + 0,273 |
| 5,0 „ + 1,0 „ | 0,707 = 0,161 | + 0,546 |
| 4,0 „ + 2,0 | 1,221 = 0,129 | + 1,092 |
| *Boden III* | Aufnehmb. Thomasmehlmengen *b* in dz/ha | |
| 6,0 kg + 0 kg | 0,640 = 0,640 | + 0,0 |
| 5,5 „ + 0,5 „ | 5,040 = 0,590 | + 4,45 |
| 5,0 „ + 1,0 „ | 9,430 = 0,530 | + 8,90 |
| *Boden IV* | | |
| 6,0 kg + 0 kg | 0,640 = 0,640 | + 0,0 |
| 5,5 „ + 0,5 „ | 2,270 = 0,590 | + 1,68 |
| 5,0 „ + 1,0 „ | 3,890 = 0,530 | + 3,36 |

Aus diesen Ergebnissen zog Mitscherlich den Schluß, daß eine Bodenverdünnung durchaus erlaubt sei, da ja mit Zuführung steigender Bodenanteile ein gradliniger Anstieg der pflanzenaufnehmbaren Nährstoffe ($P_2O_5$ bzw. $K_2O$) verbunden war. So wurde anfänglich von Mitscherlich ein Boden : Sandverhältnis von 1 : 5 gewählt, während heute bei der pflanzenphysiologischen Bodenuntersuchung ein Verhältnis von 1 : 2 üblich ist.

## HAUPTTEIL

In der Literatur sind eine Anzahl von Arbeiten veröffentlicht worden, die zu einer ablehnenden Haltung gegenüber dieser Methode gelangten. Es ist nur natürlich, daß sich besonders die Agrikulturchemiker mit diesen Problemen auseinander gesetzt

haben. Lemmermann [2], einst ein Gegner der Mitscherlichschen Auffassungen, kommt auf Grund seiner kritischen Überprüfung des „Wirkungsgesetzes" zu der Feststellung, daß es nicht ausgeschlossen erscheint, nach Beseitigung von Unstimmigkeiten mit dieser Methode die Feststellung des Düngerbedürfnisses der Böden mit einer für die Praxis ausreichenden Genauigkeit durchführen zu können. Das Urteil von Gerlach [1], der bereits vor Mitscherlich mit Gefäßdüngungsversuchen arbeitete und Rückschlüsse auf das Düngerbedürfnis des Bodens ziehen wollte ist wesentlich negativer. Er kam allerdings zu dem Schluß, daß zwar zwischen den Ergebnissen der Gefäßversuche und dem Düngebedürfnis des betreffenden Schlages gewisse Beziehungen bestehen, die Übereinstimmung zwischen Gefäß- und Feldversuchsergebnissen aber nicht so groß ist, daß man auf Grund der ersteren dem Landwirt genaue Angaben über die Art und Höhe der Düngung seiner Felder machen kann.

Gegen die Bodenverdünnung durch Sand wendet sich Gerlach besonders bei der Feststellung des Bodenstickstoffes. Hier kann ihm aus mehreren Gründen nicht widersprochen werden. Auch Mitscherlich hat die Unmöglichkeit der Bestimmung der im gewachsenen Boden vorhandenen Stickstoffmengen mit Hilfe der Gefäßmethode wegen des bei der Probeentnahme aus dem Boden auftretenden Fehlers eingesehen und zieht für die Bestimmung dieses Nährstoffes den exakten Felddüngungsversuch vor.

Im übrigen aber ging wohl Gerlach – wie sich später gezeigt hat – zu weit, wenn er auf Grund der Ergebnisse seiner Gefäßversuche behauptete, daß kein Agrikulturchemiker es wagen würde, nur auf Grund von Gefäßversuchen dem Landwirt anzugeben, wie hoch er die Düngung seiner Felder zu bemessen hat. – Gegen die Bodenverdünnung wandten sich mit einem umfangreichen Versuchsmaterial Scheffer [14] und Plate [12]. Sie verfolgten den Verlauf der *b*-Werte bei verschiedenen Boden: Sandgemischen und kamen zu dem Schluß, daß eine starke Bodenverdünnung zu überhöhten *b*-Werten führt.

Daß die Nährstoffausnutzung nicht gradlinig mit der Bodenverdünnung verläuft, hat bereits Reitmair [13] festgestellt. Auch Shalaby [15] fand bei starker Bodenverdünnung eine größere Nährstoffausnutzung. Mitscherlich [6] bestreitet prinzipiell nicht, daß durch Sandbeimengungen auf die Bodeneinheit größere Wassermengen lösend einwirken und dadurch mehr Nährstoffe in Lösung gehen können. Er hat diese Tatsache bereits 1910 [3] dargelegt.

Allerdings glaubt Mitscherlich, daß hier nicht so sehr die rein chemisch-physikalischen Bedingungen maßgebend sind, sondern vielmehr der pflanzenphysiologische Lösungsprozess der Pflanzen selbst.

Mitscherlich hat dann in den Jahren 1935 – 1939 [7] etwa 3500 Gafäßversuche zur weiteren Klärung dieser Frage durchgeführt. Dabei konnte für die Kaliversuche eine Beeinflussung der *b*-Bestimmung durch die Höhe der Sandbeimengungen nicht festgestellt werden. Die Ergebnisse der Phosphorsäureuntersuchungen ließen bei starker Bodenverdünnung etwas höhere *b*-Werte erkennen, was aber nach Mitscherlich und Dühring [11] keinen nennenswerten Einfluß auf die Ergebnisse der Bodenuntersuchungen in Gefäßen für die praktische Landwirtschaft hat. Sozusagen als „Brücke" zwischen Gefäß- und Feldversuch wurden außerdem noch Tonrohrversuche angesetzt, die in gleichsinnigen Ergebnissen zum Gefäßversuch eine Übertragung der Gefäßergebnisse auf das freie Feld als durchaus berechtigt erscheinen lassen. – Auch im Institut zur Steigerung der Pflanzenerträge, Paulinenaue, wurden in den letzten Jahren diesbezügliche Boden: Sand-Mischungsversuche durchgeführt, die zusammen mit den Versuchen von Scheffer und Mitscherlich nach etwas anderen Gesichtspunkten ausgewertet werden sollen.

Alle Versuche zeigen übereinstimmend, daß mit Zuführung steigender Bodenmengen – sowohl bei der Differenzdüngung ohne $P_2O_5$ bzw. ohne $K_2O$, als auch bei der Volldüngung – der Pflanzenertrag ansteigt. (Ausnahmen dürften auf mangelnde Wasser- und Luftführung des betreffenden Bodensubstrates zurückzuführen sein.) Dabei können die Ertragsunterschiede der korrespondierenden Versuchsglieder (Differenzdüngung zur Volldüngung bei einem bestimmten Boden : Sand-Gemisch) eng oder weit sein, je nach dem Nährstoffgehalt des betreffenden Bodens. Die Ertragsteigerung mit Zuführung verschiedener Bodenanteile setzt sich dabei aus zwei Komponenten zusammen. Einmal werden mit Steigerung des Bodenanteiles auch die im Boden vorhandenen Nährstoffmengen vermehrt, zum anderen werden aber auch (bis zu einem gewissen Grade!) die physikalischen und biologischen Eigenschaften des Boden : Sand-Gemisches verbessert. Wenn man nun für beide Komponenten mit Hilfe der logarithmischen Gleichung einen *c*-Wert berechnet, können den gefundenen Erträgen die berechneten

gegenübergestellt werden. Wir haben das getan und dabei festgestellt, daß bei allen hier zitierten Versuchen die berechneten Erträge – bis auf wenige Ausnahmen – innerhalb der dreifachen durchschnittlichen Schwankung [9] mit den gefundenen Erträgen gut übereinstimmen. Nimmt man nun die berechneten Erträge als Ausgangspunkt für die weitere Berechnung der *b*-Werte, so ist eine nachträgliche Berücksichtigung der Versuchsfehler nicht mehr notwendig.

1. *Die Versuche von Scheffer*

Scheffer hat bei seinen Versuchen meistens mit 4 verschiedenen Boden : Sand-Gemischen gearbeitet: 1 : 10 – 1,8 : 9,2 – 5,5 : 5,5 – und 11 : 0. Leider fehlt hierbei die pflanzenphysiologische *b*-Bestimmung des betreffenden Sandes (0 : 11). Dies mußte hier mit Hilfe der errechneten Wirkungswerte geschehen, wobei aus den ermittelten *a*-Werten die *b*-Mengen berechnet wurden. Man muß sich überhaupt darüber im klaren sein, daß das, was wir pflanzenphysiologisch unter dem *b*-Wert des Sandes verstehen, auch den Nährstoffgehalt des Endosperms der Körner und den Nährstoffgehalt des Gießwassers (meist Regenwasser) einschließt.

Im Institut zur Steigerung der Pflanzenerträge, Paulinenaue, wurde 1954 festgestellt, daß dabei mit folgenden Nährstoffmengen zu rechnen ist:

| Fehlerquelle | N | P | K | |
|---|---|---|---|---|
| Endosperm (Hafer | 17,0 mg | 9,5 mg | 12,6 mg | pro Gefäß |
| Hohenbockaer Quarzsand | — | 3,5 mg | 30,0 mg | pro Gefäß |
| Gießwasser (aufgef. Regenwasser) | 50,0 mg | — | 40,0 mg | pro Gefäß u. 40 *l*. im Laufe der Vegetatzt. |
| zusammen: | 67,0 mg | 13,0 mg | 82,6 mg | |

Bei einer großen Gefäßstation wie im Institut in Paulinenaue war es z.Zt. unmöglich, alle Bodenuntersuchungen mit destilliertem Wasser auf Durchlauf zu gießen. Das Regenwasser mußte dort in einem 90 cbm fassenden Zementbassin aufgefangen, und über 200 m zur Gefäßstation gepumpt werden. Die Kalimengen im Regenwasser sind durch die ungünstige Lage des Bassins zu erklären. Das Regenwasser fiel auf einen Kuhstall, auf dessen Boden Heu aufgeblasen wurde.

Diese Nährstoffmengen sind beim Stickstoff und beim Kali besonders hoch, sagen aber bzgl. ihrer künftigen pflanzenphysiolo-

gischen Wirkung nichts aus. Ihre Wirkung kann erst nach dem Experiment festgestellt werden. Wenn man so – ohne Berücksichtigung dieser Tatsachen – vom Boden : Sand-Gemisch von 1 : 10 auf 11 : 0 (also den Gesamtboden) schließt, werden sich die nun einmal vorhandenen Versuchsfehler verelffachen. (Allerdings begeht man bei der vorgeschlagenen Methode auch einen systematischen Fehler, indem der Nährstoffgehalt des Endosperms sowie des Gießwassers anteilmäßig Berücksichtigung findet, was aber exakt nicht statthaft ist.)

An einem der 10 Böden soll nun zunächst gezeigt werden, wie die Berechnung der *b*-Werte durchgeführt wurde. Bei den Kaliversuchen wurde nicht mit $c = 0{,}93$ dz/ha (Scheffer), sondern mit 0,4 dz/ha gerechnet. Als Beispiel dient der Boden 8. Die Ergebnisse sind der Tabelle II zu entnehmen.

TABELLE II

| Boden 8 | | | | | | |
|---|---|---|---|---|---|---|
| Boden : Sand Verhältnis | —P gefunden | —P ber. | —K gefunden | —K ber. | Volldg. gefunden | Volldg. ber. |
| 1 : 10 | 26,9 ± 1,1 | 27,0 | 63,9 ± 0,4 | 64,2 | 71,3 ± 0,4 | 71,7 |
| 1,8 : 9,2 | 43,5 ± 1,2 | 40,2 | 69,1 ± 0,8 | 67,0 | 72,1 ± 0,6 | 73,0 |
| 5,5 : 5,5 | 73,6 ± 2,1 | 71,4 | 72,6 ± 1,1 | 75,9 | 78,5 ± 2,5 | 78,2 |
| 11 : 0 | 83,3 ± 2,2 | 82,7 | 80,2 ± 1,4 | 81,7 | 82,3 ± 0,5 | 83,8 |
| *A* | | 85,0 | | 85,0 | | 96,0 |
| *a* | | 5,0 | | 60,0 | | 70.0 |
| *c* | | 0,14 | | 0,08 | | 0,03 |

Nachdem die Größen *A*, *a* und *c* in der von Mitscherlich angegebenen Weise [8] festgestellt wurden, konnten mit Hilfe der berechneten Erträge die *b*-Werte der einzelnen Boden : Sand-Mischungen gefunden werden. In der ersten Zeile der beiden folgenden Zusammenstellungen (Tabelle III) sind diese *b*-Werte in g/Gefäß für Phosphorsäure und Kali angegeben. Unter $-b$ sind die Nährstoffmengen zu verstehen, die pflanzenphysiologisch als systematischer Versuchsfehler anzusehen sind. (Da bei den Scheffer'schen Versuchen keine verwertbaren Sanduntersuchungen mitgeteilt wurden, mußten die $-b$-Mengen aus dem errechneten *a* [reine Sanduntersuchung] zu Hilfe genommen werden.) Werden diese Nährstoffmengen (2. Zeile) entsprechend dem Boden: Sand-Gemisch anteilmäßig in Abzug gebracht, ergeben sich in der 3.Zeile die bereinigten *b*-Werte. Um zu prüfen, ob mit steigenden Bodenanteilen ein gradliniger Anstieg der

bereinigten *b*-Werte erfolgt, sind die eingeklammerten Zahlen ( ) in der 4. Zeile beigefügt worden.

TABELLE III

| Boden : Sand | 0 : 11 | 1 : 10 | 1,8 : 9,2 | 5,5 : 5,5 | 11 : 0 |
|---|---|---|---|---|---|
| $P_2O_5$ | | | | | |
| *b* | 0,017 | 0,103 | 0,174 | 0,530 | 0,941 |
| —*b* | 0,017 | 0,015 | 0,014 | 0,009 | — |
| bereinigt | — | 0,088 | 0,160 | 0,521 | 0,941 |
| gradliniger Anstieg | — | (0,088) | (0,158) | (0,484) | (0,968) |
| $K_2O$ | | | | | |
| *b* | 0,640 | 0,737 | 0,816 | 1,151 | 1,204 |
| —*b* | 0,640 | 0,582 | 0,536 | 0,320 | — |
| bereinigt | — | 0,155 | 0,280 | 0,831 | 1,204 |
| gradliniger Anstieg | — | (0,155) | (0,279) | (0,853) | (1,700) |

In ganz der gleichen Art und Weise sind 9 Bodenuntersuchungen Scheffers berechnet worden. (Beim Boden 5 wurde von einer Berechnung der *b*-Werte abgesehen, da der Höchstertrag bei der Differenenzdüngung —P höher liegt als bei der Volldüngung.)

Aus Platzmangel und auch zur besseren Übersicht werden in den Tabellen IV und V von den übrigen Böden nur die berechneten *b*-Werte gegeben.

Die von Scheffer aus den gefundenen Erträgen berechneten *b*-Werte sind hier nicht angeführt. Sie zeigen aber alle die gleiche Tendenz, nämlich dergestalt, daß bei einem Boden : Sand-Gemisch von 1 : 5 nach erfolgter Umrechnung auf das volle Gefäßvolumen der höchste *b*-Wert erhalten wird. Ein weiterer Versuch von Scheffer (Tabelle VI) mag das deutlich machen.

Scheffer meint, daß seine Ergebnisse im Widerspruch zu Mitscherlich stehen und bezweifelt u.a. deshalb die Gültigkeit des „Wirkungsgesetzes", weil die erhaltenen *b*-Werte nach erfolgter Umrechnung auf das Gesamtgefäß Boden keine Übereinstimmung zeigen.

Wertet man aber die Scheffer'schen Versuche über die berechneten Erträge aus, so ergibt sich doch ein anderes Bild. Während einige Böden – besonders bei der Phosphorsäure – eine gute gradlinige Übereinstimmung zeigen, führt bei den meisten Böden die Umrechnung auf den Gesamtboden doch zu überhöhten *b*-Werten, allerdings nicht in dem Maße und in der Unregelmäßigkeit, wie das Scheffer feststellte. Auch die mit Hilfe von *a* errechneten

TABELLE IV

| Die Phosphorsäure-Ergebnisse | | | | | | |
|---|---|---|---|---|---|---|
| Boden | Boden : Sand | 0 : 11 | 1 : 10 | 1,8 : 9,2 | 5,5 : 5,5 | 11 : 0 |
| Nr. 1 | *b* | 0,134 | 0 22 | 0,28 | 0,51 | 0,63 |
| | —*b* | 0,134 | 0,12 | 0,11 | 0,06 | — |
| | bereinigt | — | 0,10 | 0,17 | 0,45 | 0,63 |
| | gradliniger Anstieg | — | (0,10) | (0,18) | (0,55) | (1,11) |
| Nr. 2 | *b* | 0,101 | 0,154 | 0,196 | 0,386 | 0,758 |
| | —*b* | 0,101 | 0,092 | 0,084 | 0,050 | — |
| | bereinigt | — | 0,062 | 0,112 | 0,336 | 0,758 |
| | gradliniger Anstieg | — | (0,062) | (0,112) | (0,341) | (0,682) |
| Nr. 3 | *b* | 0,193 | 0,247 | 0,289 | 0,444 | 0,539 |
| | —*b* | 0,193 | 0,176 | 0,162 | 0,097 | — |
| | bereinigt | — | 0,071 | 0,127 | 0,347 | 0,539 |
| | gradliniger Anstieg | — | (0,071) | (0,128) | (0,390) | (0.782) |
| Nr. 4 | *b* | 0,318 | 0,388 | 0,444 | 0,639 | 0,801 |
| | —*b* | 0,318 | 0,289 | 0,266 | 0,159 | — |
| | bereinigt | — | 0,099 | 0,178 | 0,480 | 0,801 |
| | gradliniger Anstieg | — | (0,099) | (0,178) | (0,544) | (1,089) |
| Nr. 6 | *b* | 0,261 | — | — | 0,392 | 0,415 |
| | —*b* | 0,261 | — | — | 0,130 | — |
| | bereinigt | — | — | — | 0,262 | 0,415 |
| | gradliniger Anstieg | — | — | — | (0,262) | (0,524) |
| Nr. 7 | *b* | 0,023 | 0,139 | 0,216 | — | 0,519 |
| | —*b* | 0,023 | 0,021 | 0,019 | — | — |
| | bereinigt | — | 0,118 | 0,197 | — | 0,519 |
| | gradliniger Anstieg | — | (0,118) | (0,212) | — | (1,298) |
| Nr. 9 | *b* | 0,030 | 0,097 | 0,148 | 0,371 | 0,726 |
| | —*b* | 0,030 | 0,027 | 0,025 | 0,015 | — |
| | bereinigt | — | 0,070 | 0,123 | 0,356 | 0,726 |
| | gradliniger Anstieg | — | (0,070) | (0,126) | (0,385) | (0,770) |
| Nr. 10 | *b* | 0,007 | 0,078 | 0,131 | 0,331 | 0,442 |
| | —*b* | 0,007 | 0,006 | 0,006 | 0,004 | — |
| | bereinigt | — | 0,072 | 0,125 | 0,327 | 0,442 |
| | gradliniger Anstieg | — | (0,072) | (0,130) | (0,398) | (0,792) |

pflanzenphysiologisch wirksamen —*b*-Mengen haben eine große Wahrscheinlichkeit für sich. (Werden sie dem Verdünnungsgrad entsprechend nicht in Abzug gebracht, lassen sich auch nicht annähernd Beziehungen zwischen dem *b* einer Bodenverdünnung und dem Gesamtvolumen finden. Meist liegen die —*b*-Werte der Differenzdüngung „ohne Kali" beträchtlich über denen „ohne

TABELLE V

Die Kali-Ergebnisse

| Boden | Boden : Sand | 0 : 11 | 1 : 10 | 1,8 : 9,2 | 5,5 : 5,5 | 11 : 0 |
|---|---|---|---|---|---|---|
| Nr. 1 | *b* | 0,20 | 0,31 | 0,38 | 0,55 | 0,57 |
| | —*b* | 0,20 | 0,18 | 0,17 | 0,10 | — |
| | bereinigt | — | 0,13 | 0,21 | 0,45 | 0,57 |
| | gradliniger Anstieg. | — | (0,13) | (0,24) | (0,71) | (1,43) |
| Nr. 2 | *b* | 0,336 | 0,441 | 0,523 | 0,813 | 0,985 |
| | —*b* | 0,336 | 0,306 | 0,282 | 0,168 | — |
| | bereinigt | — | 0,135 | 0,241 | 0,645 | 0,985 |
| | gradliniger Anstieg | — | (0,135) | (0,243) | (0,743) | (1,490) |
| Nr. 3 | *b* | 0,114 | 0,224 | 0,313 | 0,734 | 1,26 |
| | —*b* | 0,114 | 0,103 | 0,095 | 0,057 | — |
| | bereinigt | — | 0,121 | 0,218 | 0,677 | 1,26 |
| | gradliniger Anstieg | — | (0,121) | (0,218) | (0,665) | (1,33) |
| Nr. 4 | *b* | 0,479 | 0,622 | 0,736 | 1,299 | 1,794 |
| | —*b* | 0,479 | 0,436 | 0,420 | 0,240 | — |
| | bereinigt | — | 0,186 | 0,316 | 1,059 | 1,794 |
| | gradliniger Anstieg | — | (0,186) | (0,332) | (1,023) | (2,046) |
| Nr. 6 | *b* | 0,226 | — | — | 0,859 | 1,363 |
| | —*b* | 0,226 | — | — | 0,113 | — |
| | bereinigt | — | — | — | 0,746 | 1,363 |
| | gradliniger Anstieg | — | — | — | (0,746) | (1,492) |
| Nr. 7 | *b* | 0,300 | 0,433 | 0,524 | — | 0,995 |
| | —*b* | 0,300 | 0,273 | 0,252 | — | — |
| | bereinigt | — | 0,160 | 0,272 | — | 0,995 |
| | gradliniger Anstieg | — | (0,160) | (0,288) | — | (1,760) |
| Nr. 9 | *b* | 0,309 | 0,444 | 0,546 | 0,945 | 1,092 |
| | —*b* | 0,309 | 0,281 | 0,258 | 0,154 | — |
| | bereinigt | — | 0,163 | 0,288 | 0,791 | 1,092 |
| | gradliniger-Anstieg | — | (0,163) | (0,294) | (0,896) | (1,793) |
| Nr. 10 | *b* | 0,242 | 0,338 | 0,409 | 0,674 | 0,848 |
| | —*b* | 0,242 | 0,220 | 0,202 | 0,121 | — |
| | bereinigt | — | 0,118 | 0,207 | 0,553 | 0,848 |
| | gradliniger Anstieg | — | (0,118) | (0,212) | (0,649) | (1,298) |

TABELLE VI

Versuch ewiger Roggenbau Halle. Im Gefäß geprüft bei:

| Boden : Sand | *b*/kg/ha Gefäß gefunden | *b*/kg/ha Feld umgerechnet | Umrechnungs-faktor |
|---|---|---|---|
| 1 : 0 | 216 | 216 | 1 |
| 1 : 2,5 | 92 | 322 | 3,5 |
| **1 : 5** | **62** | **372** | **6** |
| 1 : 10 | 22 | 231 | 11 |

Phosphorsäure", was auch auf Grund der vorhandenen Fehlerquellen nicht anders zu erwarten war.)

Wenn man die Umrechnung auf den Gesamtboden bei jedem Boden : Sand-Gemisch durchführt, wie das Scheffer auch getan hat, so ergibt sich das Bild von Tabelle VII.

Bei dieser Auswertung der Schefferschen Versuche lassen sich doch drei wichtige Feststellungen treffen: 1.) liegen die *b*-Werte ohne Sandbeimengungen zumeist mehr oder weniger unter denen der verschiedenen Boden: Sand-Mischungen; 2.) die *b*-Werte der verschiedenen Boden : Sand-Mischungen streuen nicht unregelmäßig, sondern lassen die Tendenz erkennen, daß mit der Abnahme der Bodenmenge die Werte ansteigen und 3.) ändern sich die *b*-Wert ein den Boden : Sand-Verhältnissen von 1 : 1 bis etwa 1 : 5 nur sehr wenig. Das deutet aber darauf hin, daß das heute bebräuchliche Boden : Sand-Verhältnis von 1 : 2 vielleicht auf 1 : 3 oder sogar auf 1 : 4 erweitert werden könnte, womit die pflanzenphysiologische Bodenuntersuchungsmethode sicher noch genauer werden würde.

2. *Die Versuche von Mitscherlich*

Außer dem auf Seite 144 zitierten Boden : Sand-Mischungsversuch, liegen noch 2 weitere Boden : Sand-Mischungsversuche zur Bestimmung des Kaligehaltes von Mitscherlich [6] vor. Die *b*-Werte wurden hier nicht einfach bei den verschiedenen Boden : Sand-Verhältnissen aus der Differenzdüngung (—P bzw. —K) zur Volldüngung berechnet, sondern in jedes Boden : Sand-Gemisch wurde noch eine Nährstoffsteigerung hineingelegt. Dadurch muß naturgemäß eine bessere Fixierung der beiden hier interessierenden Punkte der Ertragskurve (*a* und *A*) eintreten. (Erwähnt sei noch, daß Mitscherlich damals 1,0 g $K_2O$ zur Erzielung des Höchstertrages verabfolgte. Heute wissen wir erfahrungsgemäß, daß 1,5 g $K_2O$ zur Erzielung des angenäherten Höchstertrages erforderlich sind.)

Die beiden Versuche wurden nun in der auf Seite 149 beschriebenen Weise verarbeitet und mit den Mitscherlich'schen Ergebnissen verglichen. (Beim Boden 2 hat Mitscherlich die pflanzenphysiologisch wirksame —*b*-Menge des Sandes vom Versuch 1 übernommen. Diese —*b*-Menge wurde hier mit Hilfe des *c*-Wertes berechnet. Der geringe Unterschied beider Werte übt aber keinen

TABELLE VII

| Umrechnung der *b*-Werte auf den Gesamtboden | | | |
|---|---|---|---|
| $P_2O_5$ | | $K_2O$ | |
| Boden : Sand-Gemisch | Gesamtboden | Boden : Sand-Gemisch | Gesamtboden |
| *Boden* 1 | | *Boden* 1 | |
| 1,0 : 10 = 0,10 | 11 : 0 = 1,10 | 1,0 : 10 = 0,13 | 11 : 0 = 1,43 |
| 1,8 : 9,2 = 0,17 | 11 : 0 = 1,04 | 1,8 : 9,2 = 0,21 | 11 : 0 = 1,28 |
| 5,5 : 5,5 = 0,45 | 11 : 0 = 0,90 | 5,5 : 5,5 = 0,45 | 11 : 0 = 0,90 |
| 11 : 0 = 0,63 | 11 : 0 = 0,63 | 11 : 0 = 0,57 | 11 : 0 = 0,57 |
| *Boden* 2 | | *Boden* 2 | |
| 1,0 : 10 = 0,062 | 11 : 0 = 0,682 | 1,0 : 10 = 0,135 | 11 : 0 = 1,490 |
| 1,8 : 9,2 = 0,112 | 11 : 0 = 0,684 | 1,8 : 9,2 = 0,241 | 11 : 0 = 1,470 |
| 5,5 : 5,5 = 0,341 | 11 : 0 = 0,682 | 5,5 : 5,5 = 0,645 | 11 : 0 = 1,290 |
| 11 : 0 = 0,758 | 11 : 0 = 0,758 | 11 : 0 = 0,985 | 11 : 0 = 0,985 |
| *Boden* 3 | | *Boden* 3 | |
| 1,0 : 10 = 0,071 | 11 : 0 = 0,782 | 1,0 : 10 = 0,121 | 11 : 0 = 1,33 |
| 1,8 : 9,2 = 0,127 | 11 : 0 = 0,776 | 1,8 : 9,2 = 0,218 | 11 : 0 = 1,33 |
| 5,5 : 5,5 = 0,347 | 11 : 0 = 0,694 | 5,5 : 5,5 = 0,677 | 11 : 0 = 1,35 |
| 11 : 0 = 0,539 | 11 : 0 = 0,539 | 11 : 0 = 1,260 | 11 : 0 = 1,26 |
| *Boden* 4 | | *Boden* 4 | |
| 1 : 10 = 0,099 | 11 : 0 = 1,089 | 1 : 10 = 0,186 | 11 : 0 = 2,046 |
| 1,8 : 9,2 = 0,178 | 11 : 0 = 1,088 | 1,8 : 9,2 = 0,316 | 11 : 0 = 1,931 |
| 5,5 : 5,5 = 0,480 | 11 : 0 = 0,960 | 5,5 : 5,5 = 1,059 | 11 : 0 = 2,118 |
| 11 : 0 = 0,861 | 11 : 0 = 0,861 | 11 : 0 = 1,794 | 11 : 0 = 1,794 |
| *Boden* 6 | | *Boden* 6 | |
| 5,5 : 5,5 = 0,262 | 11 : 0 = 0,524 | 5,5 : 5,5 = 0,746 | 11 : 0 = 1,492 |
| 11 : 0 = 0,415 | 11 : 0 = 0,415 | 11 : 0 = 1,363 | 11 : 0 = 1,363 |
| *Boden* 7 | | *Boden* 7 | |
| 1 : 10 = 0,118 | 11 : 0 = 1,298 | 1 : 10 = 0,160 | 11 : 0 = 1,760 |
| 1,8 : 9,2 = 0,197 | 11 : 0 = 1,204 | 1,8 : 9,2 = 0,272 | 11 : 0 = 1,662 |
| 11 : 0 = 0,519 | 11 : 0 = 0,519 | 11 : 0 = 0,995 | 11 : 0 = 0,995 |
| *Boden* 8 | | *Boden* 8 | |
| 1 : 10 = 0,088 | 11 : 0 = 0,968 | 1 : 10 = 0,155 | 11 : 0 = 1,700 |
| 1,8 : 9,2 = 0,158 | 11 : 0 = 0,964 | 1,8 : 9,2 = 0,280 | 11 : 0 = 1,711 |
| 5,5 : 5,5 = 0,521 | 11 : 0 = 1,042 | 5,5 : 5,5 = 0,831 | 11 : 0 = 1,662 |
| 11 : 0 = 0,941 | 11 : 0 = 0,941 | 11 : 0 = 1,204 | 11 : 0 = 1,204 |
| *Boden* 9 | | *Boden* 9 | |
| 1 : 10 = 0,070 | 11 : 0 = 0,770 | 1 : 10 = 0,163 | 11 : 0 = 1,793 |
| 1,8 : 9,2 = 0,123 | 11 : 0 = 0,752 | 1,8 : 9,2 = 0,288 | 11 : 0 = 1,760 |
| 5,5 : 5,5 = 0,356 | 11 : 0 = 0,712 | 5,5 : 5,5 = 0,791 | 11 : 0 = 1,582 |
| 11 : 0 = 0,726 | 11 : 0 = 0,726 | 11 : 0 = 1,092 | 11 : 0 = 1,092 |
| *Boden* 10 | | *Boden* 10 | |
| 1 : 10 = 0,072 | 11 : 0 = 0,792 | 1 : 10 = 0,118 | 11 : 0 = 1,298 |
| 1,8 : 9,2 = 0,125 | 11 : 0 = 0,764 | 1,8 : 9,2 = 0,207 | 11 : 0 = 1,265 |
| 5,5 : 5,5 = 0,327 | 11 : 0 = 0,654 | 5,5 : 5,5 = 0,553 | 11 : 0 = 1,106 |
| 11 : 0 = 0,442 | 11 : 0 = 0,442 | 11 : 0 = 0,848 | 11 : 0 = 0,848 |

nennenswerten Einfluß auf die weitere Berechnung aus.) Die Zusammenstellungen beider Böden sind der Tabelle VIII zu entnehmen.

TABELLE VIII

*Boden* 1

| Boden : Sand | 0 : 5 | 1 : 4 | 2 : 3 | 3 : 2 | 4 : 1 |
|---|---|---|---|---|---|
| *Berechnung nach Mitscherlich* | | | | | |
| *b* | 0,05 | 0,46 | 0,87 | 1,28 | 1,69 |
| —*b* | 0,05 | 0,04 | 0,03 | 0,02 | 0,01 |
| bereinigt | — | 0,42 | 0,84 | 1,26 | 1,68 |
| gradliniger Anstieg | — | (0,42) | (0,84) | (1 26) | (1,68) |
| *Neue Berechnung* | | | | | |
| *b* | 0,031 | 0,415 | 0,725 | 0,863 | 0,864 |
| —*b* | 0,031 | 0,024 | 0,018 | 0,012 | 0,006 |
| bereinigt | — | 0,391 | 0,707 | 0,851 | 0,858 |
| gradliniger Anstieg | — | (0,391) | (0,782) | (1,170) | (1,560) |

*Boden* 2

| Boden : Sand | 0 : 5 | 1 : 4 | 2 : 3 | 3 : 2 | 4 : 1 | 5 : 0 |
|---|---|---|---|---|---|---|
| *Berechnung nach Mitscherlich* | | | | | | |
| *b* | 0,05 | 0,11 | 0,17 | 0,23 | 0,29 | 0,35 |
| —*b* | 0,05 | 0,04 | 0,03 | 0,02 | 0,01 | — |
| bereinigt | — | 0,07 | 0,14 | 0,21 | 0,28 | 0,35 |
| gradliniger Anstieg | — | (0,07) | (0,14) | (0,21) | (0,28) | (0,35) |
| *Neue Berechnung* | | | | | | |
| *b* | 0,039 | 0,120 | 0,182 | 0,234 | 0,280 | 0,311 |
| —*b* | 0,039 | 0,032 | 0,024 | 0,016 | 0,008 | — |
| bereinigt | — | 0,088 | 0,158 | 0,218 | 0,272 | 0,311 |
| gradliniger Anstieg | — | (0,088) | (0,176) | (0,264) | (0,352) | (0,440) |

Aus den bereinigten Werten der neuen Berechnungsweise kann man ersehen, daß mit steigendem Bodenanteil kein absolut gradliniger Anstieg der *b*-Werte verbunden ist.

Faßt man auch hier die *b*-Werte der verschiedenen Boden : Sand-Mischungen nach der entsprechenden Multiplikation auf das volle Bodenvolumen zusammen, so ergibt sich folgendes Bild:

TABELLE IX

| *Boden* 1 (Umrechnung hier nur auf 4 : 1) | *Boden* 2 |
|---|---|
| von 1 : 4 = 0,391 auf 4 : 1 = 1,560 | von 1 : 4 = 0,088 auf 5 : 0 = 0,440 |
| „ 2 : 3 = 0,707 „ 4 : 1 = 1,540 | „ 2 : 3 = 0,158 „ 5 : 0 = 0,398 |
| „ 3 : 2 = 0,851 „ 4 : 1 = 1,130 | „ 3 : 2 = 0,218 „ 5 : 0 = 0,370 |
| „ 4 : 1 = 0,858 „ 4 : 1 = 0,858 | „ 4 : 1 = 0,272 „ 5 : 0 = 0,340 |
| | „ 5 : 0 = 0,311 „ 5 : 0 = 0,311 |

Bei beiden Böden tritt nach erfolgter Umrechnung eine Herabsetzung der *b*-Werte mit steigendem Bodenanteil ein. Diese Erscheinung wurde ebenfalls bei den meisten Böden von Scheffer festgestellt.

3. *Versuche im Institut zur Steigerung d. Pflanzenerträge, Paulinenaue*

Das gleiche Bild ergibt sich bei einem im Jahre 1952 in Paulinenaue durchgeführten Boden : Sand-Mischungsversuch. Hier mußte der Ertrag des reinen Sandes und entsprechend das pflanzenphysiologische $-b$ – mit Hilfe der Wirkungswerte für die $-P$, $-K$ und die Volldüngungsreihe berechnet werden. Danach sind gegenüber der Phosphorsäure fast 5mal so große Kalimengen als $-b$ in Anrechnung zu bringen, womit die pflanzenphysiologische Bedeutung der vorhandenen systematischen Versuchsfehler noch einmal unterstrichen wird.

Die ermittelten *b*-Werte sind dargestellt in Tabelle X.

TABELLE X

| Boden : Sand | 0 : 12 | 1 : 11 | 2 : 10 | 3 : 9 | 4 : 8 | 8 : 4 | 12 : 0 |
|---|---|---|---|---|---|---|---|
| $P_2O_5$ | | | | | | | |
| *b* . . . . . | 0,034 | 0,084 | 0,132 | 0,175 | 0,213 | 0,331 | 0,338 |
| $-b$ . . . . . | 0,034 | 0,031 | 0,028 | 0,025 | 0,023 | 0,011 | — |
| bereinigt . . . . . | — | 0,053 | 0,104 | 0,150 | 0,190 | 0,320 | 0,338 |
| gradliniger Anstieg . . | — | (0,053) | (0,106) | (0,159) | (0,212) | (0,424) | (0,636) |
| $K_2O$ | | | | | | | |
| *b* . . . . . | 0,161 | 0,225 | 0,284 | 0,333 | 0,372 | 0,478 | 0,500 |
| $-b$ . . . . . | 0,161 | 0,148 | 0,134 | 0,121 | 0,107 | 0,054 | — |
| bereinigt . . . . . | — | 0,077 | 0,150 | 0,212 | 0,265 | 0,424 | 0,500 |
| gradliniger Anstieg . . | — | (0,077) | (0,154) | (0,231) | (0,308) | (0,616) | (0,924) |

Auch die Auswertung dieses Boden : Sand-Steigerungsversuches beweist, daß sich die *b*-Werte mit dem Grade der Bodenverdünnung vergrößern. Vergleicht man hier das allgemein übliche Boden : Sand-Gemisch von 4 : 8 = 1 : 2 mit dem von 12 : 0 (also dem Gesamtvolumen), so ergeben sich sowohl bei der Phosphorsäure- als auch bei der Kalibestimmung beträchtliche Unterschiede.

Es folgt in Tabelle XI nun die Umrechnung vom betreffenden Boden : Sand-Gemisch auf das volle Bodenvolumen/Gefäß.

Auch diese Versuche lassen nach der neuen Berechnungsweise erkennen, daß ein gradliniger Anstieg der *b*-Werte mit Zuführung

entsprechender Bodenanteile nicht erfolgt. Ohne Sandbeimengung erhalten wir den niedrigsten *b*-Wert, während die *b*-Werte mit Zunahme der Bodenverdünnung ansteigen. Werden die *b*-Werte bereinigt, so sind die Differenzen bei den Boden: Sand-Gemischen von 1 : 2 bis 1 : 11 unerheblich.

TABELLE XI

| $P_2O_5$ | $K_2O$ |
|---|---|
| von 1 : 11 = 0,053 auf 12 : 0 = 0,636 | von 1 : 11 = 0,077 auf 12 : 0 = 0,924 |
| „ 2 : 10 = 0,104 „ 12 : 0 = 0,624 | „ 2 : 10 = 0,150 „ 12 : 0 = 0,900 |
| „ 3 : 9 = 0,150 „ 12 : 0 = 0,600 | „ 3 : 9 = 0,212 „ 12 : 0 = 0,848 |
| „ **4** : **8** = 0,190 „ 12 : 0 = **0,570** | „ **4** : **8** = 0,265 „ 12 : 0 = **0,795** |
| „ 8 : 4 = 0,320 „ 12 : 0 = 0,480 | „ 8 : 4 = 0,424 „ 12 : 0 = 0,646 |
| „ **12** : **0** = 0,338 „ 12 : 0 = 0,338 | „ **12** : **0** = 0,500 „ 12 : 0 = **0,500** |

Es drängt sich nun die Frage auf, welcher *b*-Wert die größte Wahrscheinlichkeit für sich hat. Es wäre durchaus berechtigt anzunehmen, daß der richtige *b*-Wert ohne jegliche Sandbeimengung erreicht wird, da die Erträge hier am höchsten liegen. Allerdings sind diese Höchsterträge zumeist mit einer Ertragsdepression verbunden, da ein reiner Krumenboden im Gefäß sehr leicht zum Dichtschlämmen neigt, wodurch die Wasser- und Luftführung erheblich gestört werden kann. Aus diesem Grunde geht man wohl nicht fehl, wenn dem *b*-Wert des heute üblichen Boden : Sand-Gemisches von 1 : 2 die größte Wahrscheinlichkeit zuerkannt wird, wobei eine Erweiterung auf etwa 1 : 4 bis 1 : 5 ohne wesentliche Vergrößerung der Fehlerquellen möglich wäre.

Es entspricht nun aber nicht dem Sinn dieser Methode, jede Bodenuntersuchung mit mehreren Bodensteigerungen durchzuführen. Wichtig ist, daß in jedem Jahr die pflanzenphysiologisch wirksamen —*b*-Mengen festgestellt werden, damit diese dann bei der Umrechnung auf das volle Gefäßvolumen anteilmäßig in Abzug gebracht werden können. Dazu wären 9 Gefäße mit reinem Sand notwendig; 3 mit einer Volldüngung und je 3 mit Volldüngung ohne $P_2O_5$ bzw. ohne $K_2O$.

Zum Schluß sollen einige Paulinenauer Bodenuntersuchungsergebnisse mitgeteilt werden, bei denen eine Bereinigung der *b*-Werte durchgeführt wurde. Die Bodenuntersuchungen wurden jeweils bei einem Boden : Sand-Verhältnis von 1 : 2 und 1 : 3, bzw. bei 1 : 2 und 1 : 4 durchgeführt.

Schlag V 2a (Probe 1) ist ein humoser Sandboden, der sich in

Ackernutzung befindet, während es sich bei den Proben 2–4 um reine Forstböden aus dem Schwarzwaldgebiet handelt. Errechnet man die *b*-Werte jeder Bodenuntersuchung nach der unlängst von Mitscherlich und Atanasiu angegebenen Weise [10], so ergibt sich übereinstimmend, daß bei der stärkeren Bodenverdünnung auch ein höherer *b*-Wert auftritt. Natürlich muß auch hier eine Bereinigung der *b*-Werte erfolgen, bevor die Ergebnisse der beiden Boden : Sand-Verhältnisse direkt vergleichbar sind. Nach den Erkenntnissen der vorliegenden Versuche wäre es etwa folgendermaßen möglich:

Eine Berechnung von *c*-Werten für die verschiedenen Böden und Boden : Sand-Steigerungen ist wohl kaum möglich und vor allem auch nicht notwendig, da sich zeigte, daß innerhalb des dreifachen Fehlers (bis auf wenige Ausnahmen) alle gefundenen Erträge mit den berechneten gut übereinstimmten. Zur *b*-Bestimmung werden also die tatsächlichen Erträge und ihre durchschnittlichen Schwankungen herangezogen.

Die pflanzenphysiologisch wirksamen —*b*-Mengen, die anteilmäßig in Abzug zu bringen sind, konnten aus dem in gleichen Jahre durchgeführten Phosphorsäure- und Kali-Steigerungsversuch in reinem Sand direkt errechnet werden. In diesem Falle waren 0,06 dz ha $P_2O_5$ und 0,62 dz ha $K_2O$ als —*b*-Wert für das Gesamtgefäß zu veranschlagen. (Das sind die Nährstoffmengen, die durch die Endospermwirkung, das Gießwasser und die Sandverunreinigungen pflanzenphysiologisch zur Wirkung gelangen.) Der Rechenvorgang ist nun der gleiche wie bei allen vorhergegangenen Versuchen. (Nur wird hier auf dz ha umgerechnet, was ja beim Gefäßversuch zur Feststellung der im Boden vorhandenen pflanzenaufnehmbaren Nährstoffe auch der Fall ist.)

In der folgenden Tabelle XII sind die bereinigten und unbereinigten *b*-Werte dz ha verschiedener Bodenuntersuchungen zusammengestellt.

TABELLE XII

| Lfd. Nr. | Schlag | Boden : Sand | $P_2O_5$ | | $K_2O$ | |
|---|---|---|---|---|---|---|
| | | | unberein. | bereinigt | unberein. | bereinigt |
| 1 | V 2a | 1 : 2 | 1,85 ± 0,05 | 1,74 ± 0,05 | 5,70 ± 0,10 | 4,46 ± 0,08 |
| | | 1 : 3 | 2,08 ± 0,18 | 1,84 ± 0,16 | 6,20 ± 0,03 | 4,34 ± 0,02 |
| 2 | 14 F | 1 : 2 | 0,05 ± 0 | ± 0 | 4,98 ± 0,10 | 3,74 ± 0,07 |
| | | 1 : 4 | 0,10 ± 0 | ± 0 | 7,40 ± 0,37 | 4,92 ± 0,25 |
| 3 | 52 A | 1 : 2 | 0,07 ± 0 | ± 0 | 7,26 ± 0,40 | 6,02 ± 0,33 |
| | | 1 : 4 | 0,15 ± 0 | ± 0 | 9,65 ± 0,60 | 7,17 ± 0,45 |
| 4 | 52 B | 1 : 2 | 0,05 ± 0 | ± 0 | 6,63 ± 0,57 | 5,39 ± 0,49 |
| | | 1 : 4 | 0,10 ± 0 | ± 0 | 8,30 ± 0,13 | 5,82 ± 0,09 |

Bei den Böden 2–4 kann von einer Feststellung der Phosphorsäuremengen kaum gesprochen werden, da sie einen extrem hohen $P_2O_5$-Mangel erkennen lassen. Es hat hier keinen praktischen Nutzen, ob man nun unbereinigt 5 oder 15 kg/ha $P_2O_5$ feststellt und bereinigt überall $\pm$ 0. Anders bei den Kaliwerten. Hier führte eine Bereinigung der *b*-Werte zu einer deutlichen Angleichung.

## ZUSAMMENFASSUNG

Anhand älterer und neuerer Gefäßversuche wurde besonders der Einfluß einer Bodenverdünnung durch Sandzusatz auf das Ergebnis der pflanzenphysiologischen Bodenuntersuchung nach Mitscherlich untersucht. Mit Hilfe eines errechneten Wirkungswertes für die zugeführte Bodeneinheit lassen sich den gefundenen Erträgen berechnete gegenüberstellen. Die erhaltene Übereinstimmung ist innerhalb der dreifachen durchschnittlichen Schwankung als gut zu bezeichnen. Dadurch ist eine exakte Feststellung der *b*-Werte mit steigenden Bodenanteilen möglich, ohne weitere Berücksichtigung der Versuchsfehler.

Die erhaltenen Ergebnisse lassen folgende Schulßfolgerungen zu:

1. In dem Maße, wie der Boden mit Sand verdünnt wird, steigen die *b*-Werte nach erfolgter Umrechnung auf das volle Gefäßvolumen an, so daß bei der größten Bodenverdünnung der höchste und ohne Sandbeimengung der niedrigste *b*-Wert gefunden wurde.

2. Damit erhebt sich die Frage nach dem „wahren" *b*-Wert. Obwohl die höchsten Erträge immer ohne Sandbeimengung erhalten werden, sind die daraus resultierenden *b*-Werte immer mehr oder weniger mit Depressionen behaftet, da bekanntlich die meisten Böden im Gefäß zum Dichtschlämmen neigen und dadurch die Luft- und Wasserführung leidet. Aus diesen Gründen muß man den *b*-Werten eines Boden: Sand-Gemisches von 1 : 1 oder 1 : 2 die größere Wahrscheinlichkeit zuerkennen.

3. Die Veränderungen der *b*-Werte sind innerhalb der Boden : Sand-Gemische von 1 : 2 bis etwa 1 : 5 relativ gering, so daß das heute allgemein übliche Verhältnis von 1 : 2 sicher noch erweitert werden könnte.

4. Wichtig ist, daß der *b*-Wert bereinigt werden muß. Die im *—b*-Wert – so soll er einmal bezeichnet werden – zusammengefaßten Komponenten sind die Nährstoffgehalte *a*) des Sandes, *b*) des Gießwassers und *c*) der Körner (Endospermwirkung). Durch diese Fehlerquellen gelangen besonders Kalimengen zu einer pflanzenphysiologischen Wirkung und verfälschen das Ergebnis.

5. Um in der Praxis bei der Durchführung vieler Gefäßbodenuntersuchungen die pflanzenphysiologische Wirkung dieser Fehlerquellen berücksichtigen zu können, ist eine einmalige gleichlaufende Untersuchung mit Sand durchzuführen.

6. Eine Korrektur der bislang in der üblichen Weise erhaltenen Ergeb-

nisse würde diese wohl genauer gestalten, das Wesen und den Zweck dieser Methode aber nicht entscheidend beeinflussen.

Eingegangen am 18. April 1957

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# COPPER: ITS EFFECTS ON THE GROWTH AND COMPOSITION OF THE RUBBER PLANT (*HEVEA BRASILIENSIS*)

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Copper was long recognised (Sommer [15]) as one of the essential nutrient elements required by higher plants. Investigations showed that copper was a constituent of at least three important plant enzymes and that it played a vital function in the process of respiration (Arnon [1]). But published information did not exist on the effect of a restricted copper supply on the growth and composition of the rubber plant; neither was a description of the symptoms of copper deficiency available. There was a lack of information on the effect of copper status on the concentration of rubber in the tissues. However, Beaufils and Compagnon [2 3 4 9] claimed that copper played an important role in the rubber tree's absorption of potassium from the soil and that the concentrations of copper and potassium, in the latex, were correlated.

Copper deficiency frequently occurs in plants grown on soils rich in organic matter (Gilbert [11]), particularly peat soils, such as may be found in some Malayan coastal areas. Bearing this in mind, the present studies were initiated with the following objectives; to produce and record symptoms of copper deficiency in the rubber plant; confirm some of the claims made by Beaufils (*loc. cit.*) regarding a copper-potassium interrelationship, and to determine the direct effect, if any, of copper supply on the concentration and distribution of other mineral elements and of rubber within the plant.

Rubber seedlings were grown in purified sand at varying levels of copper supply. Severe symptoms of copper deficiency were produced and the importance of the element in the nutrition of the rubber plant was established beyond doubt.

## EXPERIMENTAL METHODS

Four treatments, or levels, of copper supply were applied to the plants grown in sand:—

$Cu_1$ .... 0.001 ppm of Cu: this very low level of copper was not deliberately supplied and mainly arose from casual contamination of the nutrients.

$Cu_2$ .... 0.008 ppm of Cu: a subnormal or low level of copper.

$Cu_3$ .... 0.064 ppm of Cu (or 0.002 milligram equivalent per litre of copper): a level usually sufficient to permit healthy growth.

$Cu_4$ .... 0.512 ppm of Cu: a level anticipated to be greater than the plant's requirement but not, so it finally ensued, sufficient to induce marked toxicity effects.

Each treatment was applied in duplicate and each replicate contained five vessels (described below) in which the plants were grown.

Sifted river sand, particle size 0.5–1.5 mm, was purified by three successive seven-hour washings with a boiling mixture of (by weight) 14% hydrochloric acid and 1% oxalic acid. The purified sand was placed in 4-gallon capacity pyrex glass, freely drained vessels and subsequently well leached with water and copper-free nutrients to restore it to neutrality. The basal nutrient solution, supplied to all plants during the course of the experiment, contained the following concentrations of nutrient ions (in milligram equivalents per litre): $NH_4^+$ 3.0, $NO_3^-$ 5.0, $SO_4^{--}$ 7.5, $PO_4^{---}$ 3.0, $Mg^{++}$ 2.5, $K^+$ 3.0, $Ca^{++}$ 4.0, $Na^+$ 1.0, $Fe^{+++}$ 1.0, $Mn^{++}$ 0.02, $Zn^{++}$ 0.002, $BO_3^{---}$ 0.033, $Mo^{VI}$ 0.001, $Al^{+++}$ 0.001, $Ga^{+++}$ 0.0002, $Co^{++}$ 0.0002, $Ni^{++}$ 0.0002.

Stock solutions containing the macronutrient elements were purified by the phosphate-adsorption autoclaving process followed by subsequent dithizone extraction. Copper-free ferric citrate was prepared by combining ether-extracted ferric chloride with dithizone-extracted, copper-free, ammonium citrate. The purification procedures used were essentially those developed and used by Hewitt and Bolle-Jones [13] and which have been more fully described elsewhere (Hewitt [12]). The purified nutrients, diluted ready for application, possessed a pH of approximately 5.0.

Demineralised water, resulting from the passage of rain water through "Zeokarb", "Deacidite" and "Deminrolit" ion-exchange resins, was used for the preparation of nutrients; this water was contaminated to the extent of 0.001 ppm with copper.

Eighteen, "selfed" clone Tjirandji-1 seeds, each weighing more than four grams, were sown in each vessel in December 1954. The seedlings, after emergence were thinned out to nine plants per vessel and subsequently progressively removed at each sampling date so that by the end of the experiment, February 1956, one seedling, only remained. At each sampling (March '55, May, July, September '55, February '56) complete plants were removed and the nutrient element concentrations within roots, stems, and leaves were determined. All tap and fibrous roots of plants removed from

each replicate were bulked, dried and ground before analysis. The stems were treated similarly. Leaves were usually bulked according to storey position; some of the results are expressed as the concentration of nutrients in the dry matter of the laminae, which excluded midribs and petioles, while for the computation of the total nutrient per plant, account of the midrib and petiole composition was taken. The methods of analyses employed have been given (Bolle-Jones [5]), except for the procedure used for the determination of rubber in tissues, which was based on the method described by Meeks *et al* [14].

## VISUAL OBSERVATIONS

The first definite signs of copper deficiency appeared in the $Cu_1$ plants in April 1955; the plants were noticeably shorter than those of other treatments and showed a paling and marginal cupping of the uppermost leaves.

The symptoms first appeared near the shoot tips. Leaflets were produced which tended to remain pendulous, for longer than usual, and which developed a lime or olive-green appearance. The laminae cupped inwardly near the tip; this cupped margin turned to a grey wilted appearance (Plate I). Occasionally the cupping occurred towards the ventral surface of the lamina. The wilted margin changed to a straw-coloured or brown scorch which spread down the lamina away from the tip (Plate I). During these changes the lamina hardened but the scorch grew progressively worse. Finally the leaf would be shed; frequently a large number of leaves were shed at about the same time leaving behind a bare stem (see Plate IV). The stem growing point usually died after such a defoliation and necrosis or rotting of the stem tip was often extensive. New shoots were then put out lower down the main stem, away from the original growing point (Plate III), and the sequence of leaf expansion, cupping, scorching and abcission was repeated. In severe instances many of the lower laminae of these new side shoots did not expand at all and they become withered or atrophied prematurely so that finally a new side shoot might have several stems clothed with numerous dead and shrunken petioles, which appeared much like hairs (Plate III).

The older leaves of the $Cu_1$ plants developed a pale-green or even bright-yellow mottling which was at first marginal but then spread inwardly between the veins; this was followed by a brown tip and marginal scorch of the lamina (Plate III). Although these symptoms

PLATE I. View of topmost olive-green leaflets showing inrolled margins and tip and marginal scorch, prior to abcission.

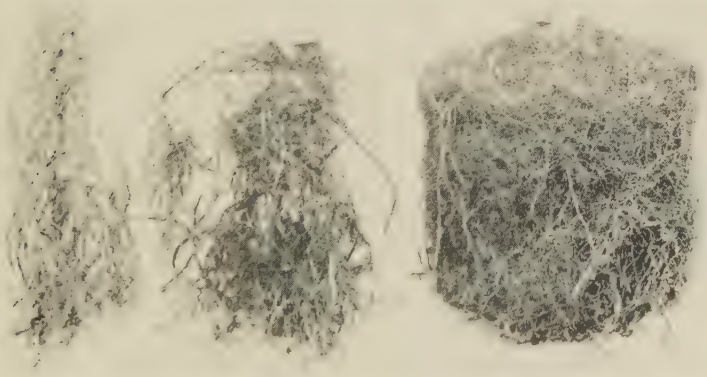


PLATE II. Roots of fourteen-month old $Cu_1$, $Cu_2$ and $Cu_3$ plants. Note weak appearance of $Cu_1$ roots and abundance of $Cu_3$ roots.

PLATE III. Shoot of $Cu_1$ plant, about 14 months old. Note numerous sideshoots, arisen as a result of terminal dieback, and scorched older leaves.

PLATE IV. $Cu_3$ plant (left), $Cu_1$ plant (right). Plants 13 months old; each scale division represents 3 inches. Note healthy growth of $Cu_3$ plant and dieback of stunted $Cu_1$ plant.

of the older leaves were relatively much more severe in their extent and occurrence in the $Cu_1$ plants they were not thought to be directly due to a deficiency of copper as similar, but milder, symptoms were seen in the older leaves of the $Cu_3$ and $Cu_4$ plants.

The symptoms in the upper region of the shoots of the $Cu_1$ plants which were most characteristic of copper deficiency, became so severe that it was necessary to supply the plants with $Cu_2$ nutrient for the period July 19–August 29, to prevent death and to resuscitate growth.

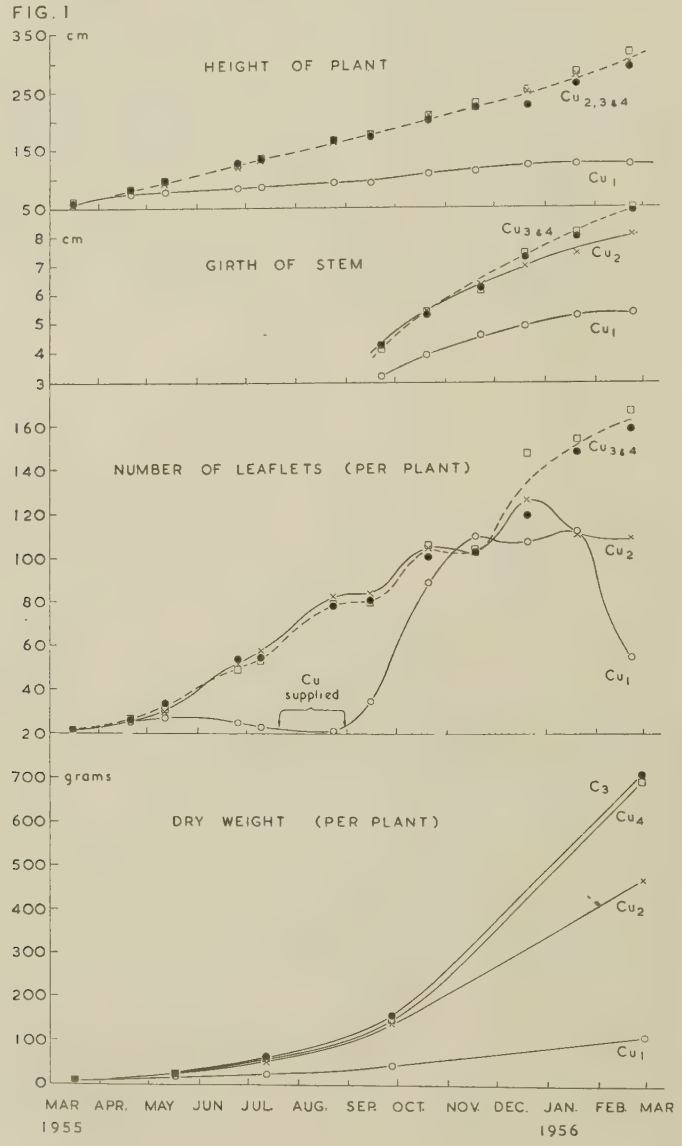
The $Cu_2$ plants suffered from a very mild deficiency of copper and olive-green young laminae with scorched edges were seen from July onwards. Severe dieback was not recorded. The $Cu_3$ plants presented a thriving appearance and appeared slightly more vigorous than the $Cu_4$ plants. Visually, the impression was gained that the tolerance of the rubber plant to a high copper level increased as the plant grew older so that any mild toxicity effects which may have been exerted on the $Cu_4$ plants in the earlier part of the experiment became less marked and the plants improved in vigour, in relation to the $Cu_3$ plants, towards the end of the experiment.

Figure 1 summarizes the effect of copper level on height, girth and number of leaflets per plant. The leaflet count values do not include the leaflets of the top storey or uppermost leaves; this method was adopted to avoid difficulties which would be encountered in deciding at which stage of development should the youngest leaves be included in the count. The girth of stems was measured 7 centimetres above sand level.

For each of these growth measurements it was obvious that the $Cu_1$ plants showed a marked inferiority to those of other copper treatments. But it was also quite clear that girth measurement and leaflet count gave a much more sensitive index to copper status than did height. Thus, towards the end of the experiment, it was possible to make a clear distinction between the $Cu_2$ and the $Cu_3$ $Cu_4$ values for girth and leaflet count, but not for height. The leaflet count records also showed (Fig. 1) the marked response by the $Cu_1$ plants to copper addition in July August 1955; a smaller and relatively less marked response was also obtained in terms of height.

The total dry weight per plant (shoot plus root) varied according to copper level (Fig. 1). The $Cu_1$ plants produced the least weight

and the $Cu_3$ the greatest. The $Cu_4$ plants were heavier than the $Cu_2$ plants but lighter than those of the $Cu_3$ treatment. The vast dis-




parity between the weights of the $Cu_1$ and $Cu_3$ plants at the end of the experiment indicated the decisive importance of copper to

the health and wellbeing of the rubber plant which were well reflected in terms of root growth and general vigour (Plates II and IV).

## CHEMICAL DATA

### *The concentration of rubber and nutrients in the tissues*

It is not feasible to present all the chemical data here. The variation in chemical composition of roots and stems at different copper levels is summarized in graphical form and the concentration values are expressed in terms of oven-dried material. The effect of copper level on laminar composition is given for the expanded laminae of the top storey only: similar effects for the laminae of other storeys are not presented as, generally, they do not add any extra information. The effect of copper level on composition of laminae might vary, as measured arithmetically, according to storey position of leaves but this usually did not alter the nature of the effect. An examination of the data, for the top storey laminae, showed that there was no obvious indication of a change in treatment effect according to data for the samplings carried out in July, September and February. The data from these samplings were therefore combined for the purposes of the statistical analyses reported here.

The concentration of copper within the roots reflected the copper status of the plant with greater amplitude than did the stems and laminae (Fig. 2). At the end of the experiment the $Cu_4$ and $Cu_1$ roots contained 246 ppm and 6 ppm of copper, respectively, as compared with values of 11 ppm and 2 ppm obtained for the corresponding stems. In general, for any one copper level at any one sampling date the roots contained a higher concentration of copper than did the laminae, which, in turn, was higher than that of the stems. The difference between the copper concentrations of $Cu_1$ and $Cu_2$ laminae was always discernible (Table I), but this was not always so for the stems (Fig. 2). As the copper-deficiency symptoms were mainly localised towards the top of the plant, it was expected that analysis would show that the younger laminae possessed a smaller concentration of copper than the older laminae. However, the analytical results did not show any well-marked trend; they indicated, for the $Cu_2$ plants, that the younger or top storey laminae possessed about the same or a slightly smaller concentration of copper than those of the older second and third

TABLE I

Rubber, chlorophyll and mineral nutrient concentrations in laminae and total amounts of rubber and minerals per plant (shoot plus root). Concentration values are means derived for the top storey leaves sampled in July, September and February and are expressed either as a % or ppm of dry matter. The total values (mg/plant) were derived from the February sampling (14-months old plants) and are each based on analysis of a total of 8 plants

| Treatment | $Cu_1$ | $Cu_2$ | $Cu_3$ | $Cu_4$ | Min. 5% Sig. Diff. |
|---|---|---|---|---|---|
| *Concentration values* | | | | | |
| Cu . . . . . ppm | 2.8 | 3.6 | 11.8 | 13.7 | 2.03 |
| Rubber (laminae) . . % | 0.50 | 0.45 | 0.39 | 0.39 | 0.19 |
| Rubber (petioles) . . % | 1.85 | 1.08 | 1.09 | 1.02 | 0.89 |
| Chlorophyll . . . . % | 0.96 | 0.94 | 1.04 | 1.05 | .054 |
| N . . . . . % | 5.12 | 4.46 | 4.52 | 4.64 | 0.21 |
| P . . . . . % | 0.56 | 0.34 | 0.34 | 0.34 | .034 |
| Mg . . . . . % | 0.31 | 0.27 | 0.26 | 0.26 | .035 |
| K . . . . . % | 1.44 | 1.28 | 1.40 | 1.38 | 0.29 |
| Ca . . . . . % | 0.38 | 0.33 | 0.30 | 0.36 | 0.14 |
| Fe . . . . . ppm | 110 | 108 | 110 | 106 | 34 |
| Mn . . . . . ppm | 56 | 31 | 30 | 39 | 4.3 |
| *Total values* (mg/plant) | | | | | |
| Cu . . . . . | 0.3 | 1.8 | 9.8 | 49.9 | |
| Rubber . . . . . | 632 | 1644 | 2455 | 2191 | |
| N . . . . . | 3324 | 9291 | 13302 | 13726 | |
| P . . . . . | 735 | 1512 | 1879 | 1950 | |
| Mg . . . . . | 318 | 1197 | 1818 | 1916 | |
| K . . . . . | 1099 | 3905 | 6777 | 6534 | |
| Ca . . . . . | 575 | 1639 | 2871 | 2732 | |
| Fe . . . . . | 36 | 167 | 476 | 457 | |
| Mn . . . . . | 8.1 | 12.6 | 18.3 | 16.8 | |

storey laminae (Table II). This difference in copper concentration was frequently not significant. Conclusive data could not be collected for the $Cu_1$ plants as during the time when symptoms were present, second and third storey leaves were not available for sampling. There was a clear indication that, for the $Cu_3$ and $Cu_4$ plants, top storey laminae possessed a higher concentration of copper than the older second and third storey laminae.

In the early sampling of March 1955 when symptoms of copper deficiency were not marked the top storey laminae of the $Cu_1$ plants possessed a copper concentration of as much as 9 ppm. As the symptoms developed and became established this concentration fell to between 2 to 3 ppm of copper. The concentration of copper in the corresponding $Cu_2$ laminae at about this time was consistent-

ly higher, and ranged between 3 to 5 ppm. Healthy top storey laminae of the $Cu_3$ plants possessed a copper concentration of at least 10 ppm (Table I).

TABLE II

Distribution of copper in laminae, according to storey position. Values based on September and February samplings and expressed as ppm of dry matter of laminae

| Storey \ Treatment | $Cu_2$ | $Cu_3$ | $Cu_4$ |
|---|---|---|---|
| Top (youngest laminae) | 3.2 | 11.5 | 13.8 |
| 2nd . . . . . | 3.0 | 10.2 | 12.5 |
| 3rd (oldest laminae) . . | 4.2 | 10.1 | 11.6 |
| Min. 5% sig. diff. . . . | 1.1 | 1.3 | 1.3 |

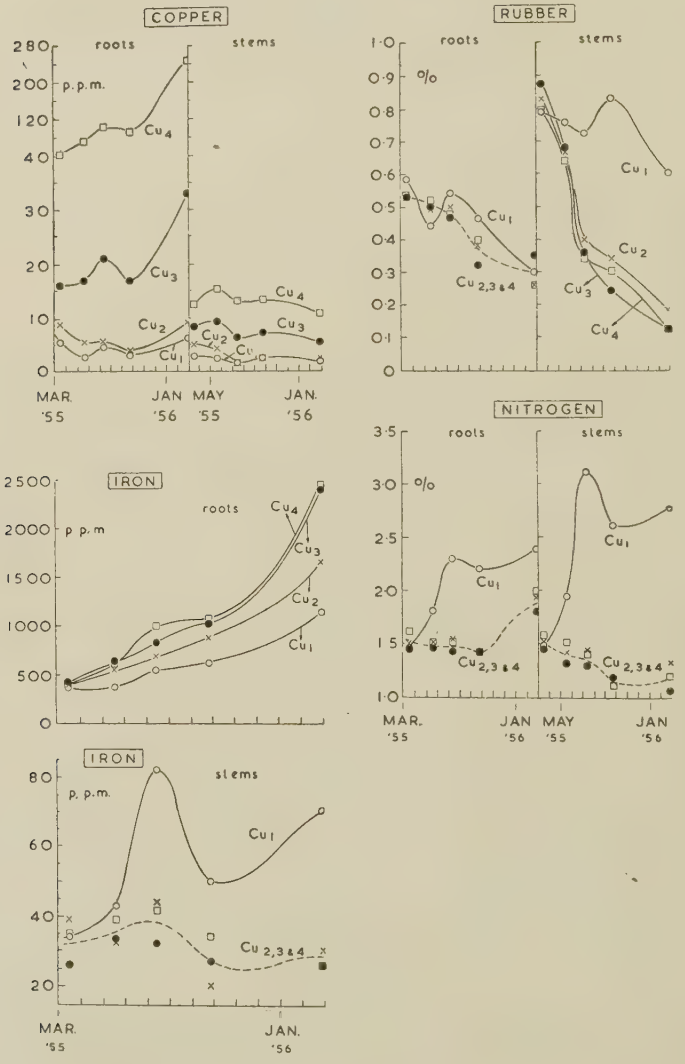
For both roots and stems the *rubber* concentration was higher in the $Cu_1$ plants than in plants grown at other copper levels; this difference was slight for the roots but well marked for the stems (Fig. 2). In addition, for the stems, it was found that the $Cu_2$ plants possessed a higher rubber concentration than the $Cu_3$ and $Cu_4$ plants, but albeit much lower than that of the $Cu_1$ plants. The concentration of rubber within the petioles was much higher in the $Cu_1$ plants than for all other treatments; a similar, but less obvious effect, was noted for the laminae (Table I). For the roots and stems there was evidence of a decline in rubber concentration as the plants grew older; such a trend was not noted for the petioles.

The concentration of chlorophyll within the top storey laminae of the $Cu_1$ and $Cu_2$ plants was less than found for the higher copper levels (Table I). This effect, although significant, was much more strongly evident in the laminae of the second and third storeys, and seemed to indicate that the positive effect of extra copper supply on chlorophyll concentration was more marked in the older laminea. For the earlier samplings, the chlorophyll concentration of the $Cu_2$ laminae was of the same order as that of the $Cu_3$ but later, when mild copper-deficiency symptoms became apparent, the concentration fell to that of the $Cu_1$ laminae. The full data are not presented here.

The concentrations of nitrogen in the roots and stems of the $Cu_1$ plants were much higher than for plants of other treatments (Fig. 2). It increased progressively with the inception and increasing

severity of the copper-deficiency symptoms; this increase did not cease until copper was supplied to the plants in July. The laminae,

FIG. 2 CONCENTRATION IN DRY MATTER

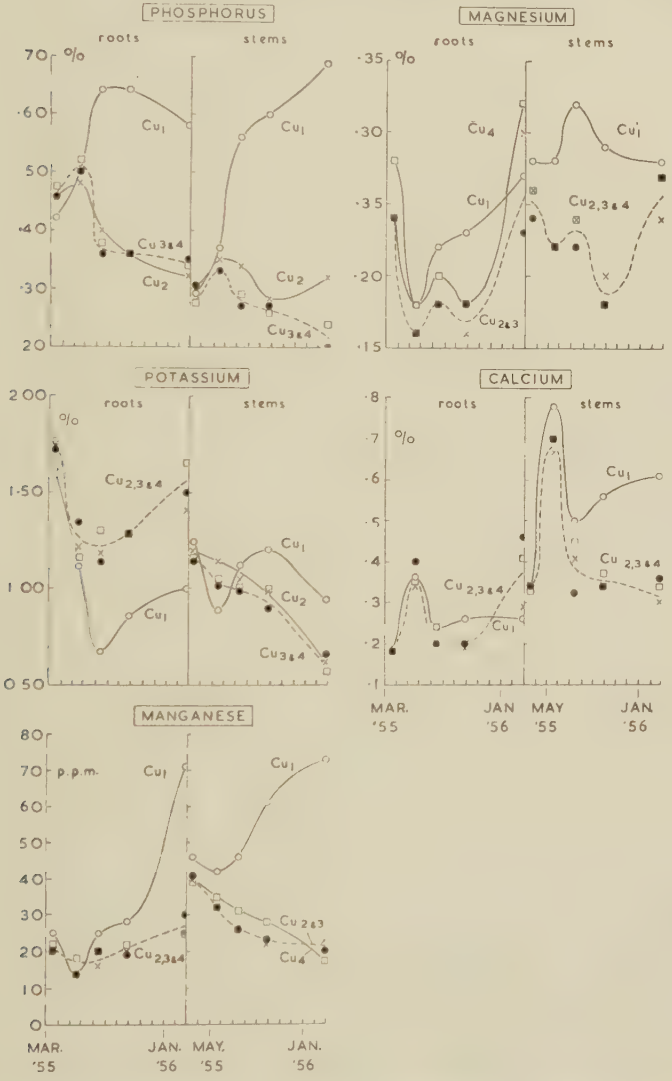



also, of the $Cu_2$, $Cu_3$ and $Cu_4$ plants contained a smaller concentration of nitrogen than did those of the $Cu_1$ plants (Table I).

As for nitrogen, the concentrations of phosphorus in the roots,

stems and laminae were much greater in the $Cu_1$ plants than in those of all other treatments (Fig. 3, Table I). The stems of the $Cu_2$

FIG. 3 NUTRIENT CONCENTRATION IN DRY MATTER




plants usually contained a higher concentration than did those of the $Cu_3$ and $Cu_4$ plants and thus showed some parallel to the variation observed for rubber.

The concentration of magnesium in the stem tissues was much higher for the $Cu_1$ plants than for those of other treatments; no consistent difference was observed between the $Cu_2$, $Cu_3$ and $Cu_4$ stem concentrations of magnesium (Fig. 3). The root tissue did not show a consistent effect of copper level on magnesium concentration which for all treatments showed a sharp initial decline in May to be followed by marked increase towards the end of the experiment. Increased copper supply significantly decreased the magnesium concentration of the laminae but this effect was generally not as well marked as the similar ones noted on nitrogen and phosphorus concentrations (Table I).

A deficiency of copper decreased the concentration of potassium found in the roots (Fig. 3); this effect was in marked contrast to those noted above and is similar for the one noted on iron concentration. For the stems, however, there were indications that the $Cu_1$ plants possessed a higher potassium concentration than found in healthy plants (Fig. 3). A significant and consistent effect of copper level on the concentration of potassium found in the laminae was not detected (Table I).

The calcium concentrations of both roots and laminae did not vary consistently with copper supply but the stems of the $Cu_1$ plants possessed a higher concentration of calcium than did those of other treatments (Fig. 3, Table I).

The level of copper supply affected the concentration of iron in the roots (Fig. 2); the iron concentration was lowest for the $Cu_1$ plants and usually increased with copper level. However, the stems of the $Cu_1$ plants contained a higher concentration of iron than did plants of other treatments (Fig. 2). A significant effect of copper level on iron concentration of laminae was not obtained (Table I).

The concentrations of manganese found in the root and stem tissues were consistently higher for the $Cu_1$ plants than for plants of other treatments (Fig. 3). Increased copper supply also significantly decreased the concentration of manganese found in the laminae (Table I).

*The relative distribution of rubber and nutrient elements in the plant*

The total amount of rubber and of each nutrient element present per plant at the February 1956 sampling is given in Table I. It is clear that the differences in tissue concentrations reported above

were insufficient to overcome the overriding beneficial effect of copper on dry weight per plant. Therefore, as the copper level increased so did the amounts of rubber and nutrients found in each plant, despite the frequently elevated concentrations of these substances found in the tissues of the $Cu_1$ plants. It was noteworthy that whereas the $Cu_4$ plants contained only about 2 to 6 times as much of nitrogen, phosphorus, magnesium, potassium, calcium and manganese as did the $Cu_1$ plants, this ratio was many times higher in regard to iron (15 times) and copper (160 times).

It is not intended to present here the full data on the distribution of nutrient elements, as affected by level of copper supply. The distribution, as a percentage of the total per plant, for any one variable showed certain trends which were best illustrated in the 1956, February sampling; these are described below and are illustrated in Figure 4. Earlier samplings showed the same trends, but were not developed to such a marked degree.

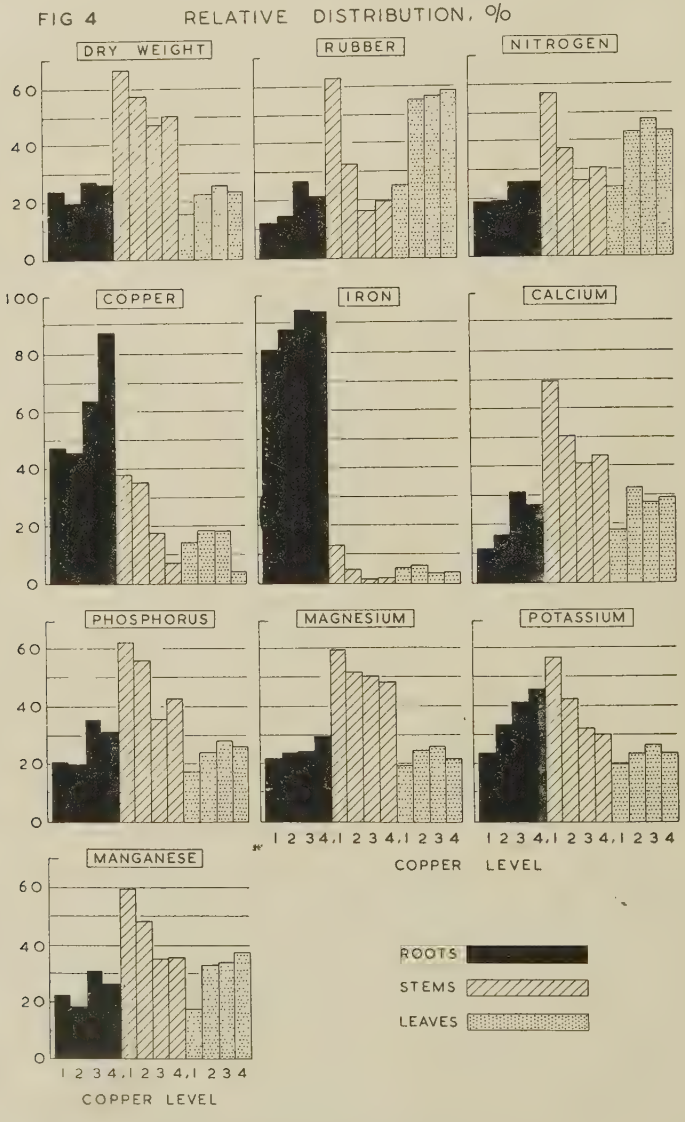
About half of the dry weight of each plant, for the February sampling, was contributed by the stems. The proportion of stem dry weight slightly decreased with increased copper level but that of leaves (laminae plus petioles) increased, while it had no consistent effect on the proportion of dry weight accounted for by the roots. The distribution of minerals did not necessarily follow this pattern and was usually strongly influenced by the copper status of the plant.

Increased copper level increased the proportion of copper distributed to the roots while it decreased that found in stems. These effects were very marked and clearly indicated the retentive influence of roots when a high level of copper was supplied to the plant.

Increased copper supply also reduced the proportion of rubber found in the stems but increased the proportions found in leaves and roots. Here, again, the effect of increased copper level was to decrease the stem root distribution ratio; for copper, this effect was largely gained by an increase in the proportion found in the roots but for rubber, the decrease in the proportion found in the stems mainly accounted for the decreased ratio.

For the other elements examined (N, P, Mg, K, Ca, Fe and Mn) the distribution, with increased copper level generally showed a diminution in the proportion found in the stems but increased proportions for roots and leaves. Frequently the proportion of any

element distributed to the $Cu_4$ leaves would be less than for the $Cu_3$ plants but this was not adjudged to be of great importance. More




than 80% of the iron in the 14-months old rubber plant was located in the roots, and this proportion increased with copper level.

## DISCUSSION

The results indicated, beyond reasonable doubt, the essentiality of copper as a nutrient element, for *Hevea brasiliensis*. An obvious similarity existed between the copper-deficiency symptoms, here described for *Hevea*, and the symptoms of dieback and exanthema reported for fruit trees (see Stiles [16] and Gilbert [11]); all were characterised by some apical defoliation and severe dieback of the branch tips. These symptoms were highly characteristic and have not been observed, in *Hevea*, under conditions of any other mineral deficiency. The inception and development of the symptoms were accompanied by a decrease in the chlorophyll concentration within the laminae as has also been noted for some other crops (see Gilbert [11]). It was noteworthy that for most of the tree crops studied (Bould, Nicholas, Tolhurst and Potter [8], Drossdoff and Dickey [10], and Stiles [16]), the threshold copper value associated with the appearance of deficiency symptoms fell within the range of 2-5 ppm of copper (in dried leaves), as compared with the 2-3 ppm. range reported here for *Hevea*. The results of the present experiment, in which plants were grown in sand, suggested that healthy laminae of *Hevea brasiliensis* should contain at least 10 ppm of copper, when expressed on a dry matter basis. Laminae of field-grown rubber plants which have been analysed in the course of advisory work fully confirmed this suggestion and gave copper values which usually ranged between 10 to 20 ppm, although some fell as low as 7 ppm.

Bould *et al* [8]. have indicated that the response of apple trees to copper application, was not always accompanied by an increase in the copper concentration of leaves when expressed as a percentage of dry matter. The present experiment showed that the concentration of copper found in the roots reflected the available supply of copper to the plant better than that found in the laminae which, in turn, furnished a slightly better index than the stems. It appeared that analysis of roots might be useful for field diagnostic purposes if the problem of soil contamination of samples could be overcome.

A significant and important fact which arose from the present experiment was that rubber plants may suffer from a mild deficiency of copper which can cause a marked reduction in dry weight of the plant (Fig. 1) but be insufficiently severe to give rise to diagnostic

foliar copper-deficiency symptoms. This was so for some of the $Cu_2$ plants and emphasised the possibility that many Malayan rubber trees may be suffering from a mild deficiency of copper, especially those grown in peat soils, and lent credence to the claims of rubber production increases, in response to soil applications of copper salts, made by Compagnon and Beaufils [9]. A severe deficiency of copper will certainly reduce the height of the rubber plant but, in general, girth and leaflet number are better indices of the plant's copper status (Fig. I). As leaflet count proves difficult in trees, girth, the traditional index of the rubber tree's health and well-being, may be employed to measure the tree's response to copper addition. The tolerance of *Hevea* to the relatively high concentration of copper (0.5 ppm) supplied in the nutrient to the $Cu_4$ plants and their improvement in vigour, in relation to the $Cu_3$ plants, towards the end of the experiment suggested that the rubber plant has a high requirement for copper. In part, this high demand may have been stimulated by the high levels of ammonium and iron ions supplied in the nutrient solution but the possibility that the rubber tree may possess a higher requirement than usually ascribed to temperate-climate plants, should not be overlooked.

Severely copper-deficient plants can only be resuscitated with difficulty; it required a six weeks period, with daily application of $Cu_2$ nutrient to allow the $Cu_1$ plants to regain some semblance of vigour. If severe copper deficiency is ever encountered under Malayan conditions it may prove a more successful curative procedure to supply repeated dosages of small amounts of copper salts rather than application of one large dosage.

A deficiency of copper reduced the concentration of potassium found in the roots (Fig. 3); a similar, and perhaps more consistent, effect was found for iron concentration (Fig. 2). This behaviour was in contrast to the accumulation of some other nutrient elements and suggested that copper status played a role in the absorption and retention of both potassium and iron by the roots. The lowest level of copper supply promoted increases in both the potassium and iron concentrations of the stem tissue as compared with plants grown at a higher level of copper supply; these increased concentrations were similar to those recorded for nitrogen, phosphorus and other elements (see Figs 2 and 3). Little evidence was available to show that the reduction, at the $Cu_1$ level of the total amount of potassium

contained per plant was of any greater significance than, for example the reduction in the total amounts of nitrogen or phosphorus per plant (Table I). All effects can readily be explained in terms of the growth reduction suffered at the $Cu_1$ level rather than to any specific relationship of potassium absorption to copper status as claimed by Beaufils and Compagnon [2 4 9]. It is, however, conceivable that once rubber trees are in tapping the drain on potassium reserves, removed in the latex, may elevate the effect of the plants copper status, as an influencing factor in the absorption of potassium by the roots, to one of controlling importance. It could then be feasibly expected that, unless copper was available in sufficient supply, the addition of potassium to the soil would be insufficient, in itself, to raise the potassium concentration of the roots to a favourable level; once this situation arose the absorption ability of the roots could become detrimentally affected.

A deficiency of copper usually: increased the concentration of nitrogen, phosphorus and manganese found in the roots; increased the stem concentrations of rubber, nitrogen, phosphorus, magnesium, potassium, calcium, iron and manganese; and increased the laminar concentrations of nitrogen, phosphorus, magnesium and manganese. These increased concentrations may be ascribed to the restrictive effect of copper deficiency on the growth of the plant which has consequently accumulated more of these elements than required for growth purposes. Therefore, these inflated values do not imply a greater absorption of these elements by copper-deficient plants which, in fact, contained much less of these nutrients, per plant, than did the healthy $Cu_3$ plants (Table I). The increased concentrations of many of these elements in the laminae must not be regarded as a specific attribute of copper deficiency as it is well established that a deficiency of any one of the essential nutrient elements will cause accumulation of others; for example a deficiency of nitrogen may cause an increased concentration of potassium and a deficiency of magnesium may promote the accumulation of manganese in the laminae of the rubber plant (Bolle-Jones [6 7]). However, the decreased concentration of potassium and iron in the roots of copper-deficient plants suggested a direct effect of copper status on the accumulation of those elements within the roots.

The parallelism between the increased tissue concentration of these various nutrient elements and that of rubber did not necessarily

signify a direct role of these elements in rubber formation. Graphs, which are not presented here, showed that with increased stem concentrations of nitrogen, phosphorus, potassium, iron and manganese, the corresponding rubber concentration also increased. Such relationships, however, seem to be incidental and do not possess any value unless it can be shown that, without large variations in total dry weight of plant, an increase in these elements would also increase the concentration of rubber. The present data did not provide such a comparison, as these increased concentrations of mineral elements and of rubber were accompanied by a marked diminution in growth and dry weight of plant under conditions of copper deficiency: that is, conditions which tend to give an inflationary influence to any values expressed in terms of concentration. Neither was there any evidence to suggest that an increased level of copper supply increased the concentration of rubber within the tissues; in fact, the opposite effect was obtained and there were no grounds whatever for assuming that copper had a major, or an exceptional, role to play in rubber synthesis.

The distribution of rubber and of nutrient elements within the plant were markedly influenced by the level of copper supply. Increased copper usually increased the proportion of rubber and of nutrients distributed to the roots; this root accumulation was most marked for copper, itself, potassium and calcium. The decline in the proportion of rubber and mineral found in the stems, as the copper supply increased, was also most striking and was well marked for most of the variables but was least noticeable for magnesium and iron. Increases in the amounts of rubber and minerals found in the leaves (laminae plus petioles) were recorded with increased copper level but the proportion of total dry weight recorded as leaves also increased with increasing copper level. However, it can be asserted with confidence, that allowing for this parallel increase in dry weight, the proportion of rubber, nitrogen, and manganese found in the leaves increased with copper level. It was also of great interest that increased copper supply could cause such a marked uptake of iron (Table I) most of which was retained in the roots.

## SUMMARY AND CONCLUSIONS

1. Rubber seedlings were grown in sand for a fourteen-month period and were supplied with four levels of copper which ranged from a very low to a high nutrient copper concentration.

2. Seedlings grown at the lowest level of copper supply ($Cu_1$ treatment) exhibited symptoms of copper deficiency which included extensive apical defoliation, severe dieback and marked stunting. The number of leaflets per plant or a measurement of stem girth proved a better and more sensitive index to copper status than did height.

3. Copper-deficient laminae possessed 2 to 3 ppm of copper, as expressed on an oven dry basis, and were characterised by much higher concentrations of nitrogen, phosphorus, magnesium and manganese and a lower concentration of chlorophyll as compared with laminae produced at a normal level of copper ($Cu_3$ treatment). It was suggested that the concentration of copper in roots provided a better guide to copper status than that of laminae.

4. Although the decreased concentration of potassium in the roots of the copper-deficient plants suggested a direct effect of copper status on the accumulation of potassium within the roots, this was insufficient reason to attribute the decreased gross potassium content per $Cu_1$ plant (as compared with a $Cu_3$ plant) to a specific effect of copper on potassium absorption, as this same effect of copper status was noted on the gross, contents of all other nutrient elements examined. However, it is pointed out that, for tapped mature trees, copper may well exert a major influence on potassium absorption, as claimed by Beaufils.

5. Increased copper supply increased greatly the amount of iron taken up by the seedlings and the proportion of iron which was distributed to the roots.

6. The distribution of rubber and of nutrient elements within the plant were markedly influenced by the level of copper supply. In general, increased copper increased the proportions of rubber and minerals distributed to the roots but decreased the proportion found in the stems. These effects were relatively less well marked for magnesium. The proportions of the total rubber, nitrogen and manganese contents, per plant, distributed to the leaves increased with copper level.

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# THE DISAPPEARANCE OF LEAF LITTER UNDER DIFFERENT WOODLAND CONDITIONS *

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[illegible]

Roudsea Wood is one of the most varied woodlands in the British Isles. It lies in the south of the English Lake District and is about five miles west of [illegible]. The area [illegible] is [illegible] one of Carboniferous limestone, the other of Silurian slate. The crest and steep of the limestone ridge are dominated by yew, whilst the eastern dip slope supports coppiced oak-ash woodland: the slate ridge, on the other hand, carries high oak-wood and coppice in which oak and birch predominate. Between the ridges there is a small tarn, now almost filled and surrounded by [illegible] marsh. To the [illegible] flows to the sea across foreshore [illegible] Morecambe Bay: whilst to the landward lie the Holker [illegible] a large area of acid peat.

The wood has long been known to naturalists and valued by them for its wide range of native woodland plants. Since its declaration as a National Nature Reserve in 1955 Roudsea Wood has become one of the main sites of research study on the ecology of woodlands for the Nature Conservancy's [illegible] Station at Grange-over-Sands. The research effort is being concentrated [illegible] soil and litter, although attention is also being given to the problem of natural regeneration of woodland. It is hoped that a concerted study of the woodland ecosystem [illegible] will [illegible] with more particularity [illegible].

## INTRODUCTION

[illegible] on the [illegible] of leaf litter [illegible] is [illegible] to study [illegible] because it is [illegible] to [illegible] the [illegible] of [illegible] all [illegible] while allowing the full range of [illegible] factors to operate. In most previous

* Roudsea Wood Nature Reserve, Publication No. 1.

studies, rigid containers of wire screening (Falconer *et al.*[2], Gustafson[3]) or of gauze fabric and wood (Lunt[5]) have been used, but by their nature these containers did not allow the experimental material to become incorporated into the natural litter layer. In the investigations of Gustafson[3] and of Lunt[5], the mesh size must have prevented entry of most of the litter mesofauna. These comments apply also to the method of Mikola[6], who placed his experimental material between layers of glass wool. Wittich[8] placed samples directly on the ground and covered them with wire-netting, a method which unfortunately does not allow the identity of the experimental material to be maintained under the conditions of our experiments. In order to minimize both these shortcomings we have used as containers untinted nylon hairnets with apertures of about 1 cm square. The flexibility of the nylon permits the enclosed leaves to become embedded in the natural litter layer and in fact to become indistinguishable from it on casual observation. In addition, nylon, unlike wood and natural fibres, has the great advantage of being biologically inert. The mesh size of the nets was sufficient to allow the entry of all but the largest litter-inhabiting invertebrates, *e.g.* some snails and beetles. All earthworms, woodlice and millipedes could enter with ease. The choice of mesh size is of necessity a compromise; one must attempt to permit access of as many elements of the biota as possible while confining the experimental material. This in itself hinders the removal of whole leaves and large leaf fragments by earthworms and reduces the movement of material by wind action, both of which may be important factors in nature.

## EXPERIMENTAL PROCEDURE

Falling leaves were collected during autumn, 1955, in nets hung beneath selected trees in Roudsea Wood. Material was obtained from the following trees, giving litter of five types: birch (*Betula verrucosa*), lime (*Tilia cordata*) and oak (*Quercus robur*), all growing on the limestone ridge; oak (*Quercus petraea*) growing on the slate ridge; birch (*Betula verrucosa*) growing on deep acid peat. This litter was dried at room temperature to a final moisture content of 10–12%. Twelve weighed samples of each of the five different litters were then placed separately in nylon nets. These nets were distributed between three sites in the Nature Reserve to give four samples of each litter per site; the twenty samples per site so obtained were arranged in four contiguous randomised blocks, each block containing all five litters. Each net

was laid on the natural litter surface at least 30 cm distant from neighbouring nets and anchored with nylon fishing-line which, in addition, held the mouths of the nets closed. The three experimental sites were surrounded by a wire netting fence to reduce gross disturbance.

The three sites, which include some examined by Pearsall [7], covered a wide range of woodland conditions.

(a) Vegetation – coppiced ash (*Fraxinus excelsior*), birch (*Betula verrucosa*) and hazel (*Corylus avellana*) with some hawthorn (*Crataegus monogyna*) beneath which was a sparse covering of *Rubus* and *Mercurialis perennis*.

Soil – a mull (Kubiena [4]) on limestone; pH 6.20–6.30 in the $A_1$ horizon. (All pH readings were taken *in situ* in moistened soil).

(b) Vegetation – coppiced oak (*Q. petraea*) and birch (*B. verrucosa*) with occasional hazel (*Corylus avellana*) and rowan (*Sorbus aucuparia*) over a thin turf of *Deschampsia flexuosa*.

Soil – a moder (Kubiena [4]) on slate; pH 3.20–3.45 in the $A_1$ horizon.

(c) Vegetation – trees of birch (*B. pubescens* and *B. verrucosa*) with occasional rowan (*Sorbus aucuparia*) over a thick layer of *Vaccinium myrtillus*.

Soil – a deep acid peat; pH 3.30–3.65 at 0–5 cms depth.

The samples were placed in the field on 21st December, 1955 (Plate I) and within a few weeks they had become incorporated into the natural litter layer (Plate II). The initial quantity of leaves per unit area (about 400 g per square metre) was of the same order as that of leaf aggregations in the L layers of the three sites. In June, 1956, the birch samples placed on mull were found to be greatly depleted; therefore on 19th June all samples were removed to the laboratory for analysis. The number of leaves remaining in each net was counted and compared with the initial number (Table I); where leaves were considerably torn and fragmented, the number of whole leaves was judged from the numbers of petioles and midribs remaining. Extraneous mineral matter and all visible animals were removed from the leaves and each sample was dried at 105°C to constant weight.

The initial oven-dry weights of all samples placed in the field were calculated by multiplying the initial air-dry weights by factors obtained from the bulk samples of the five types of litter retained in

TABLE I

Range of percentage recoveries of recognisable leaves

| Site | Mull | Moder | Peat |
|---|---|---|---|
| Birch (from limestone) | 10–42 | 98–100 | 97–100 |
| Birch (from peat) | 3–40 | 98–100 | 97–100 |
| Lime | 54–80 | 92–100 | 100 |
| *Q. petraea* | 100 | 100 | 89–100 |
| *Q. robur* | 100 | 100 | 100 |

TABLE II

Mean losses in oven-dry weight expressed as a percentage of the approximate initial oven-dry weight (1.8 g). Means ± standard errors

| Site | Mull | Moder | Peat |
|---|---|---|---|
| Birch (from limestone) | 82.9 ± 6.75 | 26.3 ± 0.84 | 27.8 ± 2.33 |
| Birch (from peat) | 91.5 ± 6.03 | 29.4 ± 0.46 | 24.8 ± 2.52 |
| Lime | 55.6 ± 3.08 | 22.6 ± 1.01 | 17.8 ± 1.56 |
| *Q. petraea* | 26.2 ± 6.80 | 23.2 ± 1.60 | 21.8 ± 0.78 |
| *Q. robur* | 17.4 ± 1.17 | 17.0 ± 0.46 | 16.7 ± 1.24 |

the laboratory and oven dried. The calculated initial oven-dry weights of all field samples approximated to 1.8 g and this figure has been used in the statistical analysis. The mean losses in oven-dry weight of the five materials on the three sites are given in Table II. Comparisons have been made, by analysis of variance, between the losses in dry weight of the same material placed on different sites and of different materials placed on the same site. The significance levels of the $t$ values so obtained are summarised in Tables III and IV.

## RESULTS AND DISCUSSION

The comparisons of litter from the same source placed on different sites are striking and unequivocal (Table III). Birch and lime

TABLE III

Significance of the differences between proportional losses in dry weight of litter from the same source on different sites

| Sites compared | Mull—Moder | Mull—Peat | Moder—Peat |
|---|---|---|---|
| Birch (from limestone) | + + + | + + + | — |
| Birch (from peat) | + + + | + + + | — |
| Lime | + + + | + + + | — |
| *Q. petraea* | — | — | — |
| *Q. robur* | — | — | — |

Probability: > 5% —; > 1 to 5% +; > 0.1 to 1% + +; ≤ 0.1% + + +

PLATE I. One [illegible] photographed in *December*, shortly after being placed on the natural litter layer of a maple site.

PLATE II. The same nets as in Plate I photographed in *February*, two months after being placed in the field.

disappeared from the nets at a far greater rate on the mull than on the other two sites; the oaks, however, showed no significant difference between sites. The differences shown by both birch and lime emphasise the great differences in biological activity between mull, on the one hand, and moder and acid peat on the other. Climatic differences can probably be discounted as the sites are less than one third of a mile apart and have similar cover. The low recoveries of recognisable leaves of birch and lime on the mull site (Table I) suggest that the activity of larger litter-feeding invertebrates, *e.g.* earthworms, slugs, snails, millipedes, and woodlice, was an important factor in the disappearance of litter from the nets. Earthworms were found to be abundant on the mull site where two species were taken, *Lumbricus terrestris* L. and *Allolobophora rosea* (Savigny); in the peat and moder sites only one species of earthworm, *Bimastus eiseni* (Levinson) was found, and that only after prolonged searching. It is interesting to note that the two species of earthworm, from the mull site are true soil burrowers whilst *B. eiseni* is usually found in the litter layer itself. It seems unlikely that either *B. eiseni* or *A. rosea* would be able to pull a whole leaf from a net, but it is probable that the more robust species, *L. terrestris*, could do so with ease.

The larger litter-feeding arthropods, as revealed by frequent pitfall trapping, show only slight differences in species composition between the three areas in Roudsea Wood selected for study. The following were found on all sites:

Diplopoda – *Glomeris marginata* (Villers)
*Polydesmus angustus* (Latzel)
*Cylindroiulus punctatus* (Leach)
Isopoda – *Oniscus asellus* L.
*Philoscia muscorum* (Scopoli)
*Trichoniscus* sp.

All however appeared to be most abundant on the mull. It has not been possible to assess the relative importance of the various faunal elements in the disappearance of litter from the nets.

Comparisons between different litters placed on the same site (Table IV) are more difficult to systematise and moreover, the validity of the comparisons between leaves of greatly different size e.g. between birch and oak, is open to question. On the mull, a clear

TABLE IV

Significances of the differences between proportional losses in dry weight of different litters on the same site

| Site | | Mull | Moder | Peat |
|---|---|---|---|---|
| Birch (from limestone) | — Birch (from peat) . . | — | + | — |
| | — Lime . . . . . | ++ | ++ | — |
| | — *Q. petraea* . . . . . | +++ | ++ | + |
| | — *Q. robur* . . . . . | +++ | +++ | ++ |
| Birch (from peat) | — Lime . . . . . | + | + | — |
| | — *Q. petraea* . . . . . | +++ | — | + |
| | — *Q. robur* . . . . . | +++ | +++ | +++ |
| Lime | — *Q. petraea* . . . . . | ++ | — | — |
| | — *Q. robur* . . . . . | ++ | ++ | + |
| *Q. petraea* | — *Q. robur* . . . . . | — | ++ | + |

Probability: $> 5\%$ —; $> 1 - 5\%$ +; $> 0.1 - 1\%$ ++; $\leqq 0.1\%$ +++

order of disappearance is evident, (*B. verrucosa* > *T. cordata* > *Q. petraea* and *Q. robur*) although the extreme position of *B. verrucosa* may be due to the small leaf size which permits easier egress from the net. On the other hand, Wittich [9] studying the decomposition of litter under mull conditions found that lime decomposed more quickly than both birch and oak, which decomposed at similar rates. On the moder in Roudsea Wood the same order (birch > lime > oak) generally applies although *Q. petraea* did not disappear significantly more slowly than either birch grown on limestone or *T. cordata*. On the peat there is little differentiation except, strikingly, that *Q. robur* disappeared more slowly than all other litters including *Q. petraea*. The extreme durability of the litter of *Q. robur* is shown also on the moder site. Differences between the two samples of *B. verrucosa* (limestone-grown and peat-grown) are significant ($P < 5\%$) only in the moder, where the peat-grown material disappeared more rapidly than the limestone material. The comparisons between these two birch litters are interesting in that they fail to show that the limestone-grown material is more attractive to heterotrophic organisms or less durable to the physical elements than is the peat-grown material. In fact there is a suggestion that the opposite may apply.

A direct estimation of the rate of disappearance of oak litter (mainly (*Q. petraea*) on a moder site was carried out in Roudsea Wood Nature Reserve (Capstick and Twinn [1]) during the same period

as the experiments described above. This showed a mean loss of dry weight over the period (December, 1955 to June, 1956) of 38%, compared with 23% loss from nylon-nets for the same species of leaf on a similar soil. More extensive comparisons are planned in order to assess the effect of the nylon nets on the rate of disappearance of litter. The technique is being used at present to follow the biological and chemical changes occurring in the course of the decomposition of oak and ash litter on two different soils in Roudsea Wood.

SUMMARY

A method is described by which quantitative studies can be made on the course of disappearance of leaf litter under woodland conditions. The litter samples are placed in the field in nylon hairnets. Results are given for a variety of litters placed on different soils.

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## LETTER TO THE EDITORS

### Micro-nutrient Deficiency and Wilting in the Radish

The influence of micronutrients upon physiological processes in plants is not yet clear. As far as the water physiology is concerned, the studies of such workers as Biebl [1], Dorfmüller [2] and Schmied [3], makes it quite clear that these substances do influence the transpiration and water economy of plants very considerably. Other workers also comment, incidentally, upon the fact that certain manurial treatments do increase or decrease the wilting of crops in the field.

However, transpiration and wilting rates are not necessarily directly proportional. These experiments were undertaken to study the wilting behaviour of radishes (*Raphanus sativus* L. *var.* Scarlet Globe) deficient in boron, copper, manganese or zinc under high-temperature conditions.

*Methods*

Radish seedlings were raised in sand cultures, using Robbins [4] solution. The deficient solutions were made by omitting the boron, copper, manganese and zinc respectively from the stock solution. The sand used was acid-washed building sand.

For the first part of the experiment, the seedlings were planted 3″ apart in trays of 24 plants. Unfortunately, in the manganese-deficient treatments not all the plants grew, so that the results were not valid. The trays were left under uniform conditions in a glasshouse with no temperature control. During the experiments the temperature fluctuated considerably, but for most of the experiments the plants endured temperatures of 45°C for five hours daily, while the minimum night temperature was 21°C.

All treatments were uniformly supplied with water, care being taken to maintain a low level of water. In order to study wilting, the water supply was stopped for two days, and then the percentage of wilted plants per treatment was measured.

Other radishes were grown in pots and treated as above. They were later removed from the sand, laid on a bench, and the time taken to wilt was measured. This is a method similar to that used by Arland [5].

*Results*

All the deficient plants wilted more rapidly than the controls. (Fig. 1). Both copper- and zinc-deficient plants wilted very rapidly and severely.

Boron-deficient plants were resistant to wilting in their youth, but as they grew older their susceptibility to wilting increased. However, even at maturity their wilting was not severe, *i.e.* while the leaves drooped and lost turgor, they did not collapse completely as did the copper- and zinc-deficient plants. The manganese-deficient radishes appeared to be as wilt resistant as the controls, but due to the small number of plants involved this is not certain.

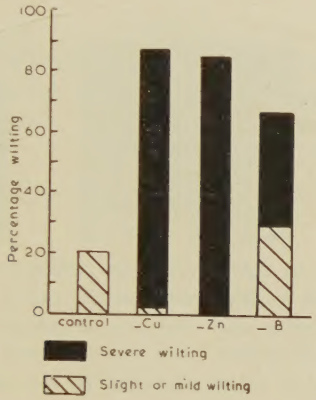


Fig. 1. Amount of wilting in radishes grown in sand culture not watered for two days. Mean of six experiments.

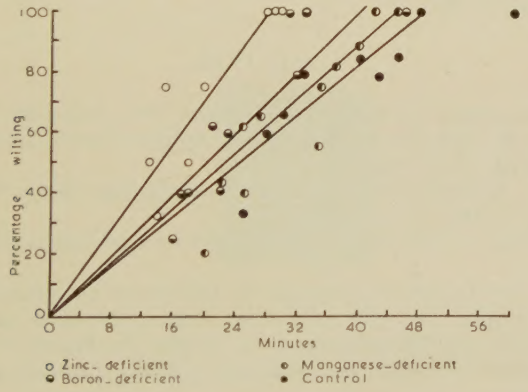


Fig. 2. Rate of wilting in mature radishes removed from sand culture. Temperature of experiment 43°C.

Mature plants grown in pots and then removed from the sand, to allow them to wilt on the bench, showed a very similar behaviour (Fig. 2). While there is a range in behaviour, the general picture is quite clear. Zinc-deficient plants, for instance, wilt much sooner than the controls. Seedlings similarly treated at 23°C responded in the same way, but the variation in wilting time was not so pronounced as in the mature plants at higher temperatures.

While the tops of the deficient plants were somewhat smaller in size than those of the controls, their root development was even more reduced, if dry weight of the root is taken as a criterion of development (cf. Table I). This may mean that water uptake is reduced due to a reduction of the absorbing area in the deficient plants. However, if there is a relationship between root weight and wilting, this is not a direct one.

TABLE I

| Dry weight of leaves and roots of deficient radishes, expressed as percentage of controls | | | | |
|---|---|---|---|---|
| Plant part | Control | Cu-deficient | Zn-deficient | B-deficient |
| Leaves | 100 | 87 | 79 | 69 |
| Roots | 100 | 62 | 58 | 58 |

*Conclusions*

Under the conditions of this experiment deficiencies of both copper and zinc greatly increase the susceptability of the radish to wilting. To a lesser extent this is true of boron and still less of manganese. These conditions are associated with a decreased root development, which could cause a reduction in the amount of water absorbed by the plant. It is unlikely that this factor is the only one involved.

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